STATEMENT

I, Futoshi Suzuki, a citizen of Japan, residing at 3D, Kopo-Shimizu, 1839 Noritake, Gifu-shi, Gifu-ken, Japan, hereby state that I am the translator of the attached document and I believe it is an accurate translation of Japanese Patent Application No. 10-095480, filed on March 24, 1998, in the name of YAMAZAKI MAZAK KABUSHIKI KAISHA.

Futoshi Suzuki

Futoshi SUZUKI
Translator
Dated this 3rd date of July, 2003

PATENT OFFICE

JAPANESE GOVERNMENT

This is to certify that the annexed is a true copy of the following application as filed with this Office.

Date of Application: March 24, 1998

Application Number: 10-095480

Applicant(s): YAMAZAKI MAZAK KABUSHIKI KAISHA

February 26, 1999

Commissioner, Patent Office Takeshi ISAYAMA

Docket Number: 11-3010345

[Title of Document] Petition For Patent

[Reference Number] 971037

[Filing Date] March 24, 1998

[To] The Commissioner of the Patent Office Hisamitsu ARAI

[International Patent Classification] B23B 47/00

[Title of the Invention] A programming aiding apparatus for a machining program

[Number of Claim] 9

[Inventor]

[Address] c/o YAMAZAKI MAZAK KABUSHIKI KAISHA Headquarter and Factories,
1, Aza-Norifune, Ohaza-Oguchi, Ohguchi-cho, Niwa-gun, Aichi-ken

[Name] Kenji SUZUKI

[Inventor]

[Address] c/o YAMAZAKI MAZAK KABUSHIKI KAISHA Headquarter and Factories
1, Aza-Norifune, Ohaza-Oguchi, Ohguchi-cho, Niwa-gun, Aichi-ken

[Name] Toshiyuki MURAKI

[Inventor]

[Address] c/o YAMAZAKI MAZAK KABUSHIKI KAISHA Headquarter and Factories
1, Aza-Norifune, Ohaza-Oguchi, Ohguchi-cho, Niwa-gun, Aichi-ken

[Name] Makoto TANAHASHI

[Inventor]

[Address] c/o YAMAZAKI MAZAK KABUSHIKI KAISHA Headquarter and Factories
1, Aza-Norifune, Ohaza-Oguchi, Ohguchi-cho, Niwa-gun, Aichi-ken

[Name] Hirokazu YOSHIDA

[Applicant for Patent Application]

[Applicant Registration No.] 000114787

[Name] YAMAZAKI MAZAK KABUSHIKI KAISHA

[Representative] Teruyuki YAMAZAKI

[Agent]

[Registration Number] 100083138

[Patent Attorney]

[Name] Shinji AIDA

[Telephone Number] 3862-7166

[List of Documents Attached]

[Name of Document] Specification 1

[Name of Document] Drawings 1

[Name of Document] Abstract 1

[Number of General Power of Attorney] 9723312

[Title of Document] Specification

[Title of the Invention] A programming aiding apparatus for a machining program

[Scope of the Invention]

[Claim 1] A programming aiding apparatus for a machining program, wherein the apparatus aids in making a modified machining program by correcting an original machining program, the original machining program including at least one machining process where a machining condition is set, with reference to a machining state variable related to the machining process, which machining state variable is obtained by executing the original program, the apparatus being characterized by:

a message storing section for storing a message that shows advice for modifying the machining condition of the machining process;

a machining state variable memory for storing the machining state variable of the machining process that is obtained by executing the original machining program;

first memory means for storing a machining efficiency judging program, wherein the machining efficiency judging program judges the machining efficiency of each machining process based on a machining efficiency judging parameter;

a machining state variable analyzing section, which, in regard to the machining process in the original machining program, analyzes the machining state variable stored in the machining state variable memory based on the machining efficiency judging program stored in the first memory means; and

a message displaying section, which selectively displays a message that is stored in the message storing section in accordance with the result of the analysis performed by the machining state variable state analyzing section.

[Claim 2] The apparatus according to claim 1, further

comprising machining process designating means for designating a machining process to be a subject of the analysis performed by the machining state variable analyzing section, and

wherein the machining state variable analyzing section, in regard to the machining process that is designated by the machining process designating means, analyzes the machining state variable stored in the machining state variable memory based on the machining efficiency judging program stored in the first memory means.

[Claim 3] The apparatus according to claim 1, further comprising:

second memory means for storing the original machining program; and

machining simulation means for performing machining simulation based on the original machining program that is stored in the second memory means,

wherein the machining state variable memory stores computed values obtained through a machining simulation performed by the machining simulation means as the machining state variable.

[Claim 4] The apparatus according to claim 1, wherein the machining state variable is the load applied to a spindle, and wherein the machining efficiency judging parameter relates to the spindle load.

[Claim 5] The apparatus according to claim 1, wherein the machining state variable is the peripheral speed of a tool, and wherein the machining efficiency judging parameter relates to the cutting speed of the tool.

[Claim 6] The apparatus according to claim 1, wherein the machining state variable is the rotating speed of a spindle, and wherein the machining efficiency judging parameter relates to the spindle rotating speed.

[Claim 7] The apparatus according to claim 1, wherein the message storing section stores a message that advises to

increase the peripheral speed of a tool such that the machining condition is modified.

[Claim 8] The apparatus according to claim 1, wherein the message storing section stores a message that advises to increase the rotating speed of a spindle such that the machining condition is modifed.

[Claim 9] The apparatus according to claim 1, wherein the message storing section stores a message that advises to change a tool such that the machining condition is modified.

[Detailed Description of the Invention]

[0001]

[Industrial Field of Application]

The present invention relates to an apparatus for aiding in programming of machining programs, which are used by machine tools.

[0002]

[Prior Art]

Numerically controlled (NC) machine tools, such as machining centers, have been known. The NC machine tools store machining conditions such as the feed rate and periheral speed of tools and the rotating speed of a spindle in a memory. To make a machining program, an operator inputs information, such as the type of tool used or the workpiece material. The input information is referred to, to select the appropriate machining conditions from the data stored in the memory. The selected machining conditions are then inserted into the machining program.

[0003]

[Problems that the Invention is to Solve]

The machining conditions stored in the memory are generalized values that can be used for various types of tools and workpiece materials. The generalized machining conditions can also be used regardless of how the machine tool clamps the workpiece or how the spindle clamps the tool. However, the generalized machining conditions are not optimal

for high speed machining. Therefore, the machining condition values are changed during programming in accordance with the capacity of the spindle motor, or the like, to make a program that enables high speed machining. However, the operator must have much knowledge and experience with regard to machine tools and cutting tools to set the appropriate machining conditions. Thus, it is difficult to set the machining conditions that are optimal for high speed machining.

[0004]

Accordingly, it is an objective of the present invention to provide an apparatus for aiding the programming of machining programs that facilitates the adjustment of machining conditions in a machining program and thereby readily produce a machining program in which machining efficiency is improved.

[0005]

[Means for Solving the Problems]

The first invention of the present invention provides a programming aiding apparatus (2) for a machining program that aids in producing a modified machining program (PRO) by correcting an original machining program (GPR). The original machining program (GPR) includes at least one machining process (KK1 to KK10) where a machining condition is set. The original machining program (GPR) is modified with reference to a machining state variable (HJ) related to the machining process (KK1 to KK10). The machining state variable (HJ) is obtained by executing the original program (GPR). The apparatus includes a message storing section (47), a machining state variable memory (12a), a first memory means (16), a machining state variable analyzing section (41, 42, 50), and a message displaying section (6, 13). The message storing section (47) stores a message (MSG) that shows advice on how to improve the machining condition of the machining process (KK1 to KK10). The machining state variable memory (12a) stores the machining state variable (HJ) of the

machining process (KK1 to KK10) that is obtained by executing the original machining program (GPR). The first memory means (16) stores a machining efficiency judging program (SR61 to SR64). The machining efficiency judging program (SR61 to SR64) judges the machining efficiency of each machining process (KK1 to KK10) based on a machining efficiency judging parameter (SF, WJ, CH, QG). The machining state variable analyzing section (41, 42, 50) analyzes the machining state variable (HJ) of the machining process (KK1 to KK10) in the original machining program (GPR) based on the machining efficiency judging program (SR61 to SR64) that is stored in the first memory means (16). The message displaying section (6, 13) selectively displays a message (MSG) stored in the message storing section (47) in accordance with the result of the analysis performed by the machining state variable analyzing section (41, 42, 50).

[0006]

The second invention of the present invention provides the apparatus (2) according to the first invention, further comprising a machining process designating means (5) that designates the machining process (KK1 to KK10) that is the subject of the analysis performed by the machining state variable analyzing section (41, 42, 50). The machining state variable analyzing section (41, 42, 50) analyzes, in regard to the machining process (KK1 to KK10) designated by the machining process designating means (5), the machining state variables (HJ) stored in the machining state variable memory (12a) based on the machining efficiency judging program (SR61 to SR64) stored in the first memory means (16).

[0007]

The third invention of the present invention provides the apparatus (2) according to the first invention as further comprising a second memory means (10) for storing the original machining program (GPR), and a machining simulation means (11) for performing machining simulation based on the

original machining program (GPR) stored in the second memory means (10). The machining state variable memory (12a) stores the computed values obtained by performing machining simulation by the machining simulation means (11) as the machining state variables (HJ).

[0008]

The fourth invention of the present invention provides the apparatus (2) according to the first invention, wherein the machining state variable (HJ) is the load applied to a spindle, and wherein the machining efficiency judging parameter (SF) relates to the spindle load.

[0009]

The fifth invention of the present invention provides the apparatus (2) according to the first invention, wherein the machining state variable (HJ) is the peripheral speed of a tool, and wherein the machining efficiency judging parameter (WJ) relates to the peripheral speed of the tool.

[0010]

The sixth invention of the present invention provides the apparatus (2) according to the first invention, wherein the machining state variable (HJ) is the rotating speed of a spindle, and wherein the machining efficiency judging parameter (CH, QG) relates to the spindle rotating speed.

[0011]

The seventh invention of the present invention provides the apparatus (2) according to the first invention, wherein the message storing section (47) stores a message (MSG) that advises to increase the cutting speed of a cutting tool such that the machining condition is modified.

[0012]

The eighth invention of the present invention provides the apparatus (2) according to the first invention, wherein the message storing section (47) stores a message (MSG) that advises to increase the rotating speed of a spindle such that

the machining condition is modified.

[0013]

The ninth invention of the present invention provides the apparatus (2) according to the first invention, wherein the message storing section (47) stores the message (MSG) that advises to change a cutting tool such that the machining condition is modified.

[0014]

The reference numerals enclosed within parentheses are conveniently fed for showing the corresponding elements in the drawings. The present invention is not limited to the drawings.

[0015]

[Embodiment]

A preferred embodiment of the present invention will now be described with reference to drawings.

Fig. 1 is a block diagram showing a control apparatus for a machining center having a navigation apparatus as a programming aiding apparatus according to the present invention;

Fig. 2(a) is a graph showing machining timing data;

Fig. 2(b) is a table showing the processing procedures;

Fig. 2(c) is a diagram showing sub-routine numbers table;

Fig. 2(d) is a diagram showing machining state information;

Fig. 3 is a flowchart showing the contents of a navigation program;

Fig. 4 is a flowchart showing the contents of a sub-routine 61R;

Fig. 5 is a flowchart showing the contents of a sub-routine 62R;

Fig. 6 is a flowchart showing the contents of a sub-routine 63R;

Fig. 7 is a flowchart showing the contents of a sub-

routine 64R;

Fig. 8 is a diagram showing a navigation data file;

Fig. 9 (a) is a diagram showing a basic cutting speed upper-limit file SYF1;

Fig. 9(b) is a diagram showing a cutting speed upper-limit coefficient file SKF1;

Fig. 9(c) is diagram showing a basic cutting speed upper-limit file SYF2;

Fig. 9(d) is a diagram showing a cutting speed upper-limit coefficient file SKF2;

Fig. 9(e) is diagram showing a basic cutting speed upper-limit file SYF3;

Fig. 9(f) is a diagram showing a cutting speed upper-limit coefficient file SKF3; and

Fig. 10 is a graph showing the output characteristics of the spindle relative to the rotating speed.

[0016]

As shown in Fig. 1, a machining center 1 has a control unit 100. The control unit 100 includes a navigation apparatus 2. The navigation apparatus 2 has a main controller 3. The main controller 3 is connected to various devices by buses. Such devices include a keyboard 5, a display 6, a programmer 7, a tool data memory 9, a machining program memory 10, a machining simulator 11, a simulation data manager 12, a display controller 13, a machining navigator 15, a system program memory 16, a tool number determiner 17, a tool number memory 19, a variable memory 20, a sub-routine number selector 21, a sub-routine number table memory 22, a sub-routine number determiner 23, a sub-routine executor 25, a processing completion determiner 26, a subject tool determiner 27, a subject tool number memory 29, a tool diameter determiner 40, a spindle load determiner 41, a cutting speed determiner 42, a basic cutting speed upper-limit file memory 43, a cutting speed upper-limit coefficient file memory 45, a cutting speed upper-limit value calculator

46, a navigation information memory 47, a navigation information manager 49, and a rotating speed determiner 50. A simulation result data memory 12a is connected to the simulation data manager 12.

[0017]

With the above-constituted machining center 1 and control unit 100 thereof, a machining program PRO is made as follows. An operator first inputs information, such as the tool number of the tool or tools that will be used for machining, the material of the workpiece subject to machining, and the type of machining that is to be carried out with a device such as the keyboard 5. The tool data memory 9 stores a tool data file KDF, which is known in the art. The tool data file KDF is formed by tables of data. A data table is provided for each cutting tool number. Each table includes information related to the associated cutting tool, such as the type and material of the cutting tool, the appropriate feed rate and cutting speed of the cutting tool, and the appropriate rotating speed of the spindle to which the cutting tool is attached. The programmer 7 refers to the tool data file KDF, which is stored in the tool data memory 9, and determines the machining conditions (machining condition) such as feed rate, cutting speed, and spindle rotating speed of each designated cutting tool based on the information that is related to the tool number and material of the workpiece subject when these information is input through the keyboard 5. The programmer 7 uses the determined machining conditions to make a machining program GPR with a known automatic programming method. The machining program GPR is then stored in the machining program memory 10. In this embodiment, the machining program PRO is made by improving part of the machining program GPR.

[0018]

After completion and storage of the machining program GPR, the operator inputs a command through the keyboard 5 to

simulate the machining program GPR. The main controller 3 receives the command and executes the machining simulation with the machining simulator 11. The machining simulator 11 then reads the machining program GPR, which is stored in the machining program memory 7, to execute the machining simulation using a simulation method known in the art. During the execution of the machining simulation, the machining simulator 11 transmits simulation result information KJ, which is related to the machining simulation, to the simulation data manager 12 using a method known in the art. The simulation data manager 12 stores the simulation result information KJ in the simulation result data memory 12a and further transmits the information KJ to the display controller 13. The display controller 13 then displays the information KJ on the display 6 as numerical figures and graphs. An example of the machining processes included in the machining program GPR is shown in Fig. 2(a). In this case, cutting tools numbered T1 to T10 are employed. The cutting tools T1 to T10 sequentially perform machining processes KK1 to KK10, respectively. The simulation result information KJ includes machining time data SJ, which indicates the initiating time and terminating time of each machining process. Accordingly, the information shown on the display 6 includes the machining time data SJ, which is displayed as a graph like that shown in Fig. 2(a). In addition to the machining time data SJ, the simulation result information KJ includes values of machining state information HJ, which indicates the state of the spindle and tool in each machining process KK1 to KK10, as machining state variables. The values of machining state information HJ may be in the form of a table, such as that shown in Fig. 2(d), indicating the maximum spindle load, the tool cutting speed, and the spindle rotating speed in each machining process KK1 to KK10, in correspondence with each cutting tool number T1 to T10. The maximum spindle load indicates the maximum value of the

torque load acting on the spindle during machining relative to the tolerated maximum torque load of the spindle. The maximum spindle load is shown with the measure of percentage. The tool cutting speed is indicated in units of meters per minute. The spindle rotating speed is indicated as rotation per minute.

[0019]

Upon completion of the machining simulation, the operator inputs a machining navigation command C1 with the keyboard 5. The main controller 3 receives the command C1 and executes machining navigation with the machining navigator 15. The machining navigator 15 reads out a navigation program NPR (Fig. 3), which is stored in the system program memory 16, to execute the machining navigation. As shown in Fig. 3, when initiating machining navigation, the machining navigator 15 commands the display controller 13 to generate a message demanding the designation of a machining process. The display controller 13 then displays the message (not shown) on the display 6 demanding the designation of the machining process that is to be subjected to machining navigation (step STP1). The operator is designated to the subject machining process by inputting the number of the cutting tool used in that process (step STP1). When designating the subject machining process, the operator refers to a graph, or the like, including the machining time data SJ in Fig. 2(a), which is shown on the display 6, to locate the machining process that should undergo machining navigation. For example, the operator selects the machining process for which the machining time is relatively long. The operator then inputs the number assigned to the cutting tool used in the selected machining process with the keyboard 5, or the like. For example, in Fig. 2(a), the machining time of machining processes KK2, KK5, KK8, and KK10 that correspond to the tool numbers T2, T5, T8, and T10, respectively, are relatively long. In this case, the operator inputs the corresponding

tool numbers T2, T5, T8, and T10 with the keyboard 5, or the like. At that time, the tool number determiner 17 determines whether or not the tool numbers have been input with the keyboard 5, or the like (step STP2). If the tool numbers T2, T5, T8, T10 are determined to have been input with the keyboard 5, or the like, the determiner 17 determines that the input of the tool numbers have completed and outputs a determination result S1.

[0020]

If the determination result S1 is output, the machining navigator 15 stores the input tool numbers T2, T5, T8, T10 in a tool number memory 19 (step STP3). As shown in Fig. 2(b), the tool number memory 19 includes a processing table STB that assigns a sequential processing ordinal number (1st, 2nd, 3rd, and so forth) to each tool. The machining navigator 15 sets an ordinal variable i, which is stored in the variable memory 20, to an initial value of 1 (step STP4). The machining navigator 15 commands the sub-routine number selector 21 to select the number of a sub-routine (step STP 5). The sub-routine number selector 21 first commands the subject tool determiner 27 to determine the type of the subject cutting tool in the first process. The subject tool determiner 27 refers to the processing table STB (Fig. 2(b)), which is stored in the tool number memory 19, according to the current value of the ordinal variable i, which is stored in the variable memory 20. For example, if the variable i indicates the initial value of 1, the tool that is to be used first in the processing table STB of Fig. 2(b) is selected. In this case, the tool number assigned to ordinal number 1 is T2. Furthermore, the subject tool determiner 27 determines the type of the cutting tool corresponding to the selected tool number T2 by referring to the tool data file KDF, which is stored in the tool data memory 9. The assigned cutting tool is a drill, for example. The subject tool determiner 27 stores the tool number T2 corresponding to the ordinal

variable i in the variable memory 20, or the tool number T2 that is the number of the cutting tool used in the first process, in the subject tool number memory 29. The sub-routine number table memory 22 stores a sub-routine number table VTB, which indicates a sub-routine number corresponding to each type of cutting tool with a form of a table, as shown in Fig. 2(c). When the subject tool determiner 27 determines the tool type of the tool number T2, the sub-routine number selector 21 refers to the sub-routine number table VTB to select the sub-routine number assigned to the determined cutting tool type. For example, if the cutting tool assigned to the selected tool number T2 is a drill, the sub-routine number selector 21 selects sub-routine number 61 from the sub-routine number table VTB of Fig. 2(c).

[0021]

The sub-routine number determiner 23 determines whether or not the sub-routine number selector 21 has selected a sub-routine number (step STP6). If it is determined that a sub-routine number has been selected, the sub-routine number determiner 23 outputs a determination result S2. In the navigation program NPR, four sub-routines SR61, SR62, SR63, and SR64, which are selectively executed, are included in step STP7, which is executed on completion of step STP6. The sub-routines SR61, SR62, SR63, and SR64 correspond to the sub-routine numbers 61, 62, 63, and 64 shown in Fig. 2(c). When the determination result S2 is output, the machining navigator 15 executes the sub-routine that corresponds to the selected sub-routine number (step STP7). For example, if the sub-routine number that is selected by the sub-routine number selector 21 is 61, the first sub-routine SR61, shown in Fig. 4, is executed. If it is determined that a sub-routine number has not been selected in step STP6, the sub-routine number determiner 23 outputs a non-selection determination result S3. For example, if the cutting tool type is a reamer, the sub-routine number selector 21 cannot select a sub-routine number

since the sub-routine number table VTB of Fig. 2(c) does not include the tool type. When the determination result S3 is output, step STP7 is not carried out as shown in Fig. 3. In such case, the machining navigation proceeds to step STP8, which is described later. In other words, machining processes performed by cutting tools that are not included in the sub-routine number table VTB of Fig. 2(c) such as a boring bar are not subject to machining navigation.

[0022]

In the flowchart of this embodiment shown in Fig. 3, a plurality of machining processes are assigned at the same time and the machining navigation of these steps are sequentially automatically performed. However, only one machining process may be assigned and the machining navigation thereof may be performed soon after the assignation is completed. That is, the operator refers to a graph, or the like, indicating the machining time data SJ shown in Fig. 2(a), selects one machining process that is to be the subject of the machining navigation and inputs the tool number of the machining process with the keyboard 5, or the like. The subject tool determiner 27 determines the tool type of the tool number T2 referring to the sub-routine number table VTB of the tool data file memory 9 based on the input tool number. The sub-routine number selector 21 determines the sub-routine number that corresponds to the type of the selected tool referring to the sub-routine number table VTB. The machining navigator 15 executes the sub-routine that corresponds to the determined sub-routine number. When the processes of the sub-routine are completed and the messages are displayed, and so forth, a part of the machining program is improved in accordance with the messages, which is described later. Afterward, the following sequential steps are repeated. One machining process that is to be the subject of the machining navigation is input. The sub-routine number that corresponds to the input tool number is determined. The

sub-routine process that corresponds to the determined sub-routine number is executed. A part of the machining program is improved in accordance with the displayed message. This enables machining navigation and correction of the machining program for a plurality of machining processes. It is obvious that one machining process is repeatedly input to undergo machining navigation and correction of the machining program of the machining process.

[0023]

Now, the description returns to the first embodiment. The processes of the sub-routines and correction of the machining program, which is described later, are common to the above-described case. In the sub-routine SR61, which is illustrated in Fig. 4, the machining navigator 15 commands the tool diameter determiner 40 to determine the diameter of the selected cutting tool. The tool diameter determiner 40 then refers to the tool data file KDF, which is stored in the tool data memory 9, to determine the diameter of the subject cutting tool T2. The tool diameter determiner 40 then judges whether or not the diameter of the subject tool assigned to the tool number T2, or a drill, is equal to or greater than 3 mm (step STP101). If the diameter of the cutting tool is determined not to be equal to or greater than 3 mm, or the diameter of the cutting tool is smaller than 3 mm, it is difficult to change the cutting speed of the tool since the diameter of the cutting tool is too small. Thus, the machining navigator 15 terminates the sub-routine SR61 without executing the machining navigation. If the diameter of the cutting tool is determined to be 3mm or greater, the spindle load determiner 41 determines the load applied to the spindle (step STP102). More specifically, the spindle load determiner 41 refers to the values of machining state information HJ, which is stored in the simulation result data memory 12a, to determine the maximum spindle load (60%, in this case) by the cutting tool T2, or the drill, which is

stored in the subject tool number memory 29. The spindle load determiner 41 then judges whether or not the maximum spindle load is equal to or lower than a predetermined upper-limit value SF. The upper-limit value SF is one of the parameters used to determine the machining efficiency and may be set, for example, at 80%. Furthermore, the upper-limit value SF may be changed arbitrarily before executing the navigation program NPR. If the maximum spindle load during machining by the drill is determined not to be equal to or lower than the upper-limit value SF, or the maximum spindle load is greater than 80%, the machining navigator 15 terminates the sub-routine SR61 without executing the machining navigation. That is, since, in the machining process KK2, it is not necessary to further improve the machining efficiency, a message MSG, which is described later, or the like is not displayed. If the maximum spindle load during machining by the drill is equal to or smaller than the limit value SF at step STP102, the spindle load can be further increased. Thus, the cutting speed determiner 42 determines the cutting speed of the cutting tool (step STP103).

[0024]

More specifically, the cutting speed determiner 42 refers to the values of machining state information HJ, which is stored in the simulation result data memory 12a, to determine the cutting speed of the tool (40.8 m/sec, in this case) assigned to the tool number T2, which is stored in the subject tool number memory 29 of the machining process KK2. The basic cutting speed upper-limit file SYF1, which is illustrated in Fig. 9(a), is stored in the basic cutting speed upper-limit file memory 43. The basic cutting speed upper-limit file SYF1 indicates the cutting speed upper-limit value (m/min) of the drill for different types of workpiece materials (FC, FCD, S45C and so forth). The cutting speed upper-limit coefficient file SKF1 is stored in the cutting speed upper-limit coefficient file memory 45, as shown in Fig.

9(b). The cutting speed upper-limit coefficient file SKF1 includes a plurality of tables ta1, ta2, ta3, and so forth, as shown in Fig. 9(b). Each table corresponds to one of the workpiece materials listed in the basic cutting speed upper-limit file SYF1 (FC, FCD, S45C and so forth). Each table indicates the cutting speed upper-limit coefficient (%) for different types of cutting tool materials including HSS, carbide, and coated HSS, and so forth, or the compensation coefficient for the basic cutting speed upper-limit value. The cutting tool materials in this embodiment includes different types of cutting parts of the cutting tools such as HSS and carbide, different types of tool structure including a coolant-through tool having passages through which coolant flows, and different types of tool usage including throw away, that is disposable tools. The calculator 46 refers to the machining program GPR stored in the machining program memory 10 to determine the material of the subject workpiece. The calculator 46 also refers to the cutting tool data file KDF in the cutting tool data memory 9 to determine the material of the cutting tool assigned with the tool number T2 of the machining process KK2, which is stored in the subject tool number memory 29. Afterward, the calculator 46 selects the basic cutting speed upper-limit value that corresponds to the material of the workpiece from the basic cutting speed upper-limit file SYF1, which is stored in the basic cutting speed upper-limit file memory 43. The calculator 46 further selects the cutting speed upper-limit coefficient corresponding to the selected tool material based on the tool material and the cutting speed upper-limit coefficient file SKF1, which is stored in the cutting speed upper-limit coefficient file memory 45. The calculator 46 then multiplies the selected basic cutting speed upper-limit value with the selected cutting speed upper-limit coefficient to obtain the cutting speed upper-limit value WJ (m/min). Accordingly, the type and material of the cutting tool (drill) used for machining and

the material of the subject workpiece are taken into consideration when computing the limit value WJ. For example, if the material of the workpiece is FC and the material of the cutting tools is carbide, the basic cutting speed upper-limit value is 30 m/sec and the cutting speed upper-limit coefficient is 220%, as shown in Figs. 9(a) and 9(b), respectively, and the cutting speed upper-limit value WJ is 66 m/min, accordingly. In the preferred embodiment, the limit value WJ (which is the same for an end mill and a face mill) is obtained by only multiplying the basic cutting speed upper-limit value and the cutting speed upper-limit coefficient. However, conditions such as the diameter of cutting tools, cutting width and depth, hardness of workpiece, and how cutting tools are grasped, may be taken into consideration when computing the limit value WJ.

[0025]

At step STP103, the cutting speed determiner 42 judges whether or not the cutting speed of the drill is equal to or lower than the limit value WJ, which is computed by the cutting speed upper-limit value calculator 46. The navigation information memory 47 stores navigation information such as that shown in Fig. 8. The navigation data includes 10 messages MSG, each assigned with a different navigation information number of 1 to 10. The table of Fig. 8 lists exemplary messages. Thus, the messages are not limited to those of Fig. 8 and may be changed as required. The messages MSG show specific advice to the operator for improving the machining program GPR to perform faster machining and to improve the machining efficiency. If it is determined that the cutting speed of the tool is higher than the cutting speed limit value WJ in step STP103, this indicates that the spindle load may still be increased (step STP102). However, the cutting speed of the tool, which has been designated in the machining program GPR, cannot be increased since it has already exceeded the limit value WJ. In such case, the sub-

routine proceeds to step STP104. The navigation information manager 49 reads out the message MSG designated as navigation information number 2 from the navigation information memory 47 and transmits the message MSG to the display controller 13. The display controller 13 then displays the received message MSG on the display 6 (step STP104). As shown in Fig. 8, the message MSG assigned with number 2 advises changing the cutting tool material so that the cutting speed may be increased. The message MSG shown in the drawing is an example and may be changed in accordance with the conditions of how the workpiece is mounted and tooled. Specifically, in the machining process KK2, the maximum spindle load is equal to or lower than the spindle load upper-limit value SF. The cutting speed of the cutting tool, the material of which is selected in the machining program GPR, is, however, higher than the cutting speed upper-limit value WJ. A change in the material of the cutting tool changes the cutting speed upper-limit value WJ, or the cutting speed upper-limit coefficient, to permit an increase in the spindle load and high-speed machining. Accordingly, the increased cutting speed upper-limit value WJ permits an increase in the cutting tool speed. The message MSG of navigation information number 2 is displayed. For example, under the assumption that the material of the subject cutting tool commanded by the operator in the machining program GPR is carbide, the cutting speed upper-limit coefficient of which is 220%, as shown in Fig. 9(b), the message MSG is obtained such that the cutting tool is changed to a coolant-through tool having passages through which coolant flows, the cutting speed upper-limit coefficient of which is 460%, as shown in Fig. 9(b). The coolant-through tool is assumed to have a spindle through hole that has a passage through which coolant flows in the spindle. A change in the machining condition of the machining program GPR in accordance with the message MSG enables faster machining. Thus, upon completion of the navigation program

NPR, the operator can improve the machining conditions of the subject machining process in the machining program GPR in accordance with the message MSG that appeared on the display 6. For example, the message MSG designated as number 2 that appears on the display 6 advises the operator to change the cutting tool material so that the cutting speed can be increased. Specifically, if the material of the cutting tool before the machining condition is improved is carbide, the cutting tool is changed to a coolant-through tool having a spindle through hole, which increases the cutting speed. Accordingly, the cutting speed upper-limit value in the machining program PRO is increased and the cutting speed may be increased within the range of the load tolerated by the spindle. This permits faster machining. As described above, the navigation apparatus 2 advises the operator on how the machining program can be improved by displaying a message MSG on the display 6. Thus, the operator can easily make a machining program that permits high speed and efficient machining just by following the advice given by the navigation apparatus 2.

[0026]

If the cutting speed determiner 42 determines that the cutting speed is lower than the cutting speed upper-limit value WJ in step STP103, the spindle load and the cutting speed can both be increased (step STP102). In this case, the navigation information manager 49 reads out the message MSG that corresponds to navigation information number 1 from the navigation information memory 47 and transmits the message MSG to the display controller 13. The display controller 13 then displays the received message MSG on the display 6 (step STP105). As shown in Fig. 8, the message MSG designated as number 1 indicates that the cutting speed may be increased to the limit value. It is preferred that the limit value WJ, which is computed by the calculator 46, be shown on the display 6 in addition to the message MSG (number 1). That is,

the maximum spindle load is equal to or lower than the spindle load upper-limit value SF and the cutting speed is equal to or lower than the cutting speed upper-limit value WJ in the machining process KK2. Accordingly, the cutting speed may be increased to the cutting speed upper-limit value WJ within the range of the tolerated spindle load and cutting speed for performing faster machining. The message MSG (number 1) that appears on the display 6 advises the operator to increase the cutting speed within the range defined by the machining condition upper-limit value WJ. Accordingly, the operator can improve the machining conditions of the machining process KK2 in the machining program GPR by increasing the cutting speed within the range defined by the cutting speed upper-limit value WJ in accordance with the message MSG designated as number 1. Correction of the machining program PRO increases the cutting speed in the subject machining process. Thus, machining is performed with high speed.

[0027]

The sub-routine SR61 is completed when either step STP104 or step STP105 is finished, as shown in Fig. 4. The machining navigation proceeds to step STP8, as shown in Fig. 3, upon completion of the sub-routine SR61. At step STP8, the processing completion determiner 25 judges whether or not the ordinal variable i stored in the variable memory 20 has reached a maximum value (four in this case), which is shown in Fig. 2(b). If it is determined that the ordinal variable i is one and has not reached four, step STP9 is performed. In step STP9, the machining navigator 15 adds one to the variable i in an incremental manner. Thus, the variable i becomes two. Afterward, the processing returns to step STP5, as shown in Fig. 3. The machining navigator 15 commands the sub-routine number selector 21 to select the number of a sub-routine. The sub-routine number selector 21 commands the subject tool determiner 27 to determine the type of cutting

tool that is the subject of the second machining process. The subject cutting tool is a roughing end mill, for example. Subsequently, the selection of the sub-routine number assigned to the determined tool type is carried out referring to the sub-routine number table VTB. In this case, the sub-routine number is 62, as shown in Fig. 2(c). At that time, the subject tool determiner 27 stores the tool number T5 corresponding to the variable i in the variable memory 20, which is the number assigned to the cutting tool used in the second process.

[0028]

The sub-routine number determiner 23 determines whether or not the sub-routine number selector 21 has selected a sub-routine number (step STP6) and outputs a selection completion signal S2. When the selection completion signal S2 is output, the machining navigator 15 executes the sub-routine SR62 (shown in Fig. 5) that has the selected sub-routine number (62) (step STP7). In the sub-routine SR62, the machining navigator 15 commands the spindle load determiner 41 to determine the load applied to the spindle, as shown in Fig. 5 (step STP7). The process in step STP201 is the same as that of step STP102 in the sub-routine SR61. When the maximum load applied to the spindle by the roughing end mill is greater than the spindle load upper-limit value SF (e.g., 80% in this embodiment), the cutting speed determiner 42 determines the cutting speed (step STP202).

[0029]

The process in step STP202 is the same as that of step STP103 in the sub-routine SR61. At step STP202, the cutting speed determiner 42 determines the cutting speed by the roughing end mill based on the tool number T5, which is stored in the subject tool number memory 29, and the spindle condition information HJ, which is stored in the simulation result information memory 12a. In this case, the cutting speed is 100.4 m/min. The basic cutting speed upper-limit

file SYF2, which is illustrated in Fig. 9(c), is stored in the basic cutting speed upper-limit file memory 43. The basic cutting speed upper-limit file SYF2 indicates the basic cutting speed upper-limit value (m/min) of the end mill for different types of workpiece materials (FC, FCD, S45C, and so forth). The cutting speed upper-limit coefficient file SKF2 is stored in the cutting speed upper-limit coefficient file memory 45, as shown in Fig. 9(d). The cutting speed upper-limit coefficient file SKF2 includes a plurality of tables td1, td2, td3, and so forth, as shown in Fig. 9(d). Each table corresponds to one of the workpiece materials listed in the basic cutting speed upper-limit file SYF2 (FC, FCD, S45C, and so forth). The cutting speed upper-limit coefficient file SKF2 indicates the cutting speed upper-limit coefficient (%) of the end mill for different types of cutting tool materials including HSS, carbide, and coated HSS, and so forth, or the compensation coefficient for the basic cutting speed upper-limit value. The calculator 46 refers to the machining program GPR stored in the machining program memory 10 to determine the material of the subject workpiece. The calculator 46 also refers to the cutting tool data file KDF in the cutting tool data memory 9 to determine the material of the cutting tool of tool number T5, which is stored in the subject tool memory 29. Afterward, the calculator 46 selects the basic cutting speed upper-limit value that corresponds to the material of the workpiece from the basic cutting speed upper-limit file SYF2, which is stored in the basic cutting speed upper-limit file memory 43. The calculator 46 further selects the cutting speed upper-limit coefficient that corresponds to the selected tool material based on the tool material and the cutting speed upper-limit coefficient file SKF2, which is stored in the cutting speed upper-limit coefficient file memory 45. The calculator 46 then multiplies the selected basic cutting speed upper-limit value with the selected cutting speed upper-limit coefficient to obtain the

cutting speed upper-limit value WJ (m/min). Accordingly, the material of the cutting tool used for machining and the material of the subject workpiece are taken into consideration when computing the limit value WJ.

[0030]

The cutting speed determiner 42 judges whether or not the cutting speed by the end mill that is determined at step STP202 is equal to or lower than the computed cutting speed upper-limit value WJ calculated by the calculator 46. If the determiner 42 determines that the cutting speed is higher than the cutting speed upper-limit value WJ, the rotating speed determiner 50 determines the spindle rotating speed. More specifically, the rotating speed determiner 50 refers to the tool number T5 stored in the subject tool number memory 29 and the values of spindle state information HJ stored in the simulation result data memory 12a to determine the spindle rotating speed of the end mill in the machining process KK5 (401 rpm, in this case). The rotating speed determiner 50 determines whether the spindle rotating speed is equal to or lower than a predetermined base value CH (step STP203). The base value CH is one of the parameters used to judge machining efficiency. If the spindle rotating speed reaches the base value CH, the output of the spindle becomes maximum and is maintained at a constant value. If the rotating speed determiner 50 determines that the spindle rotating speed is higher than the base value CH in step STP203, this indicates that the spindle load cannot be increased (step STP201), the cutting speed cannot be further decreased (step STP202), and that the maximum output of the spindle cannot be increased even if the spindle rotating speed is further increased. That is, the output of the spindle is maintained at a constant value. In such case, the speed of the machining process in the machining process KK5 cannot be further improved. Thus, the sub-routine SR62 is terminated without displaying the message, or the like. If

the rotating speed determiner 50 determines that the spindle rotating speed is equal to or lower than the base value CH in step STP203, this indicates that, although the spindle load and cutting speed cannot be further increased (steps STP201 and STP202), the maximum output of the spindle may be increased if the spindle rotating speed is increased. That is, the torque of the spindle is maintained at a constant value. In such case, the navigation information manager 49 reads out the message MSG that corresponds to navigation information number 4 from the navigation information memory 47 and transmits the message MSG to the display controller 13 (step STP204). The display controller 13 then displays the received message MSG on the display 6. As shown in Fig. 8, the message MSG assigned with number 4 advises the operator to change the material of the cutting tool to increase the cutting speed. The message MSG explains, as shown in Fig. 8, that the cutting speed may be increased if the material of the cutting tool is changed. That is, in the machining process KK5, the maximum spindle load is greater than the spindle load upper-limit value SF (within the range between 80% and 100%, for example). When machining is performed using the cutting tool selected in the machining program GPR, the cutting speed increases above the cutting speed upper-limit value WJ, but the rotating speed of the spindle is equal to or lower than the base value CH. Accordingly, if the cutting tool material is changed, the cutting speed upper-limit value WJ is increased. That is, if the cutting tool material is changed, the cutting speed upper-limit coefficient is increased. The cutting speed of the tool can be increased as long as the spindle load does not exceed the spindle load limit value, accordingly. The message MSG designated as number 4 advises on the display 6 that the material of the cutting tool is changed to increase the cutting speed, as shown in Fig. 8. For example, if the subject cutting tool designated in the machining program GPR is a small diameter cutting tool, the

material of which is HSS, the compensation coefficient is 25%, as shown in Fig. 9(d). In such case, when the message MSG designated as number 4 appears on the display 6, the operator is notified that the cutting speed may be increased by changing the material of the cutting tool from HSS to carbide. If carbide is used, the compensation coefficient is 100%, as shown in Fig. 9(d). The sub-routine SR62 is terminated after executing step STP204. When the machining program GPR is improved, which is described later, the machining condition is changed such that the material of the cutting tool that is used in the machining process KK5 is changed in accordance with the message MSG designated as number 4 shown on the display 6 to increase the cutting speed of the cutting tool. For example, in the machining program GPR, the material of the cutting tool is changed from HSS to carbide to increase the cutting speed of the cutting speed. In the machining program PRO, the cutting speed upper-limit value is increased in the machining process KK5 and the cutting speed is increased within the range of the load tolerated by the spindle. This permits faster machining.

[0031]

If the cutting speed determiner 42 determines that the cutting speed by the end mill is equal to or lower than the cutting speed upper-limit value WJ at step STP202, the rotating speed determiner 50 judges whether or not the rotating speed by the spindle of the end mill is equal to or lower than the base value CH, which is performed in the same manner as step STP203 (step STP206). At step STP205, the rotating speed determiner 50 determines that the rotating speed of the spindle is higher than the base value CH, it indicates that the spindle load cannot be increased (step STP201) but the cutting speed can be increased (step STP202). In such case, the output of the spindle is maintained at a constant value. Accordingly, the machining cannot be improved even if the cutting speed and the spindle rotating speed are

increased. The sub-routine SR62 is thus terminated without showing a message, or the like. If the rotating speed determiner 50 determines that the rotating speed of the spindle is equal to or lower than the base value CH, it indicates that the spindle load cannot be increased (step STP201) but the cutting speed can be increased (step STP202). In such case, the torque of the spindle is maintained at a constant value. The navigation information manager 49 reads out the message MSG that corresponds to navigation information number 3 from the navigation information memory 47 and transmits the message MSG to the display controller 13. The display controller 13 then displays the received message MSG on the display 6 (step SPT206). The message MSG advises that the cutting speed can be increased to the cutting speed upper-limit value, as shown in Fig. 8. That is, in the machining process KK5, the maximum spindle load is greater than the spindle load upper-limit value SF (within the range between 80% and 100%, for example), the cutting speed is equal to or lower than the cutting speed upper-limit value WJ and the rotating speed of the spindle is equal to or lower than the base value CH. Accordingly, if the cutting speed is increased as long as the spindle load does not exceed the spindle load percentage, the high-speed machining is performed. The message MSG designated as number 3 advises on the display 6 that the cutting speed is increased to the cutting speed upper-limit value, as shown in Fig. 8. The sub-routine SR62 is terminated after executing step STP206. When the machining program GPR is improved, which is described later, the machining condition is improved such that the cutting speed in the machining process KK5 is increased to the cutting speed upper-limit value WJ in accordance with the message MSG designated as number 3 shown on the display 6. In the machining program PRO, the cutting speed is increased in the machining process KK5. This permits faster machining.

[0032]

When it is determined that the maximum spindle load by the end mill is equal to or lower than the spindle load upper-limit value SF at step STP201, it indicates that the maximum spindle load is equal to or lower than the value of 80%. The cutting speed determiner 42 judges the cutting speed, which is performed in the same manner as step STP202 (step STP207). When the cutting speed determiner 42 determines that the cutting speed is higher than the cutting speed upper-limit value WJ at step STP207, it indicates that the spindle load can be increased (step STP201) but the cutting speed may be above the cutting speed upper-limit value WJ if the machining is performed using the cutting tool selected in the machining program GPR. The navigation information manager 49 reads out the message MSG that corresponds to navigation information number 4 from the navigation information memory 47 and transmits the message MSG to the display controller 13. The display controller 13 then displays the received message MSG on the display 6 (step SPT208). The message MSG advises that the material of the cutting tool is changed to increase the cutting speed. That is, in the machining process KK5, the maximum spindle load is equal to or lower than the spindle load upper-limit value SF, but the cutting speed is higher than the cutting speed upper-limit value WJ. If the cutting tool material is changed to increase the cutting speed upper-limit value WJ (that is, the cutting speed upper-limit coefficient), high-speed machining is performed. The cutting speed increases as long as the cutting speed does not exceed the cutting speed upper-limit value WJ. The message MSG designated as number 4 advises on the display 6 that the material of the cutting tool is changed to increase the cutting speed, as shown in Fig. 8. The sub-routine SR62 is terminated after executing step STP208. In such case, when the machining program GPR is improved, which is described later, the machining condition is changed such that the material of the cutting tool used in the machining process

KK5 is changed to increase the cutting speed in accordance with the message MSG designated as number 4 shown on the display 6. In the machining program PRO, the cutting speed upper-limit value is increased in the machining process KK5. The cutting speed is increased as long as it does not exceed the cutting speed upper-limit value. This permits faster and efficient machining.

[0033]

When the cutting speed determiner 42 determines that the cutting speed by the end mill is equal to or lower than the cutting speed upper-limit value WJ at step STP207, it indicates that the spindle load and the cutting speed can be increased (step STP201). The navigation information manager 49 reads out the message MSG that corresponds to navigation information number 3 from the navigation information memory 47 and transmits the message MSG to the display controller 13. The display controller 13 then displays the received message MSG on the display 6 (step SPT209). The message MSG advises that the cutting speed can be increased to the cutting speed upper-limit value, as shown in Fig. 8. That is, in the subject machining process, the maximum spindle load is equal to or lower than the spindle load upper-limit value SF, and the cutting speed is equal to or lower than the cutting speed upper-limit value WJ. If the cutting speed is increased in accordance with the cutting speed upper-limit value, the faster machining is performed. The message MSG designated as number 3 advises on the display 6 that the cutting speed is increased to the cutting speed upper-limit value WJ, as shown in Fig. 8. The sub-routine SR62 is terminated after executing step STP209. When the machining program GPR is improved, which is described later, the machining condition is changed such that the cutting speed is increased as long as it does not exceed the cutting speed upper-limit value WJ in the machining process KK5 in accordance with the message MSG designated as number 3 shown on the display 6. In the

machining program PRO, the cutting speed is increased in the machining process KK5. This permits faster and efficient machining.

[0034]

Step STP8 is performed, as shown in Fig. 3, upon completion of the sub-routine SR62. At step STP8, the processing completion determiner 25 judges whether or not the ordinal variable i stored in the variable memory 20 has reached a maximum value (four in this case), which is shown in Fig. 2(b). If the processing completion determiner 25 determines that the ordinal variable i is two and has not reached four, step STP9 is performed. In step STP9, the machining navigator 15 adds one to the variable i in an incremental manner. Thus, the variable i becomes three. Afterward, the processing returns to step STP5, as shown in Fig. 3. The machining navigator 15 commands the sub-routine number selector 21 to select the number of a sub-routine. The sub-routine number selector 21 commands the subject tool determiner 27 to determine the type of the cutting tool that is used in the third machining process. The subject cutting tool is a roughing face mill, for example. Subsequently, the selection of the sub-routine number assigned to the determined tool type is carried out referring to the sub-routine number table VTB. In this case, the sub-routine number is 63, as shown in Fig. 2(c). At that time, the subject tool determiner 27 stores the tool number T8 corresponding to the variable i in the variable memory 20, which is the number of the cutting tool used in the third process, in the subject tool number memory 29.

[0035]

The sub-routine number determiner 23 determines whether or not the sub-routine number selector 21 has selected a sub-routine number (step STP6) and outputs a selection completion signal S2. When the selection completion signal S2 is output, the machining navigator 15 executes the sub-routine SR63

(shown in Fig. 6) that has the selected sub-routine number (63) (step STP7). In the sub-routine SR63, the machining navigator 15 commands the spindle load determiner 41 to determine the load applied to the spindle, as shown in Fig. 6 (step STP301). The process in step STP301 is the same as that of step STP201 in the sub-routine SR62. When the maximum spindle load by the face mill is greater than the spindle load upper-limit value SF (e.g., 80%), the cutting speed determiner 42 determines the cutting speed (step STP302).

[0036]

The process in step STP302 is the same as that of step STP203 in the sub-routine SR62. At step STP302, the cutting speed determiner 42 determines the cutting speed by the face mill based on the tool number T8, which is stored in the subject tool number memory 29, and the spindle state information HJ, which is stored in the simulation result information memory 12a. In this case, the cutting speed is 110.9 m/min. The basic cutting speed upper-limit file SYF3, which is illustrated in Fig. 9(e), is stored in the basic cutting speed upper-limit file memory 43. The basic cutting speed upper-limit file SYF3 indicates the basic cutting speed upper-limit value (m/min) of the face mill for different types of workpiece materials (FC, FCD, S45C, and so forth). The cutting speed upper-limit coefficient file SKF3 is stored in the cutting speed upper-limit coefficient file memory 45, as shown in Fig. 9(f). The cutting speed upper-limit coefficient file SKF3 includes a plurality of tables tf1, tf2, tf3, and so forth, as shown in Fig. 9(f). Each table corresponds to one of the workpiece materials (FC, FCD, S45C, and so forth) listed in the basic cutting speed upper-limit file SYF3. The cutting speed upper-limit coefficient file SKF2 indicates the cutting speed upper-limit coefficient (%) of the face mill for different types of cutting tool materials including carbide, cermet, and coated carbide, and so forth, or the compensation coefficient for the basic

cutting speed upper-limit value. The cutting speed upper-limit value calculator 46 refers to the machining program GPR stored in the machining program memory 10 to determine the material of the subject workpiece. The calculator 46 also refers to the cutting tool data file KDF in the cutting tool data memory 9 to determine the material of the cutting tool based on the tool number T8, which is stored in the subject tool number memory 29. Afterward, the calculator 46 selects the basic cutting speed upper-limit value that corresponds to the material of the workpiece from the basic cutting speed upper-limit file SYF3, which is stored in the basic cutting speed upper-limit file memory 43. The calculator 46 further selects the cutting speed upper-limit coefficient that corresponds to the selected tool material based on the tool material and the cutting speed upper-limit coefficient file SKF3, which is stored in the upper-limit cutting speed coefficient file memory 45. The calculator 46 then multiplies the selected basic cutting speed upper-limit value with the selected cutting speed upper-limit coefficient to obtain the cutting speed upper-limit value WJ (m/min). Accordingly, the material of the cutting tool used for machining and the material of the subject workpiece are taken into consideration when computing the limit value WJ.

[0037]

The cutting speed determiner 42 judges whether or not the cutting speed of the face mill that is selected at step STP302 is equal to or lower than the cutting speed upper-limit value WJ calculated by the calculator 46. If the determiner 42 determines that the cutting speed is higher than the cutting speed upper-limit value WJ, the rotating speed determiner 50 determines whether or not the spindle rotating speed is equal to or lower than the base value CH, which is carried out in the same manner as step STP303 in the sub-routine SR62 (step STP303). If the spindle rotating speed reaches the base value CH, the spindle load and the cutting

speed cannot be increased (steps STP 301 and 302) and the output of the spindle is maintained at a constant value. In such case, the machining process cannot be improved even if the cutting speed and the rotating speed of the spindle are further increased. Thus, the sub-routine SR63 is terminated without showing a message, or the like. If the rotating speed determiner 50 determines that the spindle rotating speed is equal to or lower than the base value CH in step STP303, this indicates that, although the spindle load and cutting speed cannot be further increased (steps STP301 and STP302), the torque of the spindle is maintained at a constant value. In such case, the navigation information manager 49 reads out the message MSG that corresponds to navigation information number 6 from the navigation information memory 47 and transmits the message MSG to the display controller 13. The display controller 13 then displays the received message MSG on the display 6 (step STP304). As shown in Fig. 8, the message MSG advises the operator to change the material of the cutting tool to increase the cutting speed. Specifically, although the maximum spindle load is greater than the spindle load upper-limit value SF (e.g. in the range between 80% and 100%, for example) and the cutting speed is higher than the cutting speed upper-limit value WJ in the machining process KK8, the spindle rotating speed is equal to or lower than the base value CH. If the cutting tool is changed to increase the cutting speed upper-limit value WJ (that is, the cutting speed upper-limit coefficient), the cutting speed can be increased as long as it does not exceed the spindle load percentage. The message MSG designated as number 6 advises on the display 6 that the material of the cutting tool is changed to increase the cutting speed, as shown in Fig. 8. For example, if the material of the cutting tool designated in the machining program GPR is carbide, the cutting speed upper-limit coefficient of which is 100%, as shown in Fig. 9(f), the message advises that the material is changed to

coated carbide, the cutting speed upper-limit coefficient of which is 115%, as shown in Fig. 9(f). The sub-routine SR63 is terminated after executing step STP304. When the machining program GPR is improved, which is described later, the machining condition is changed such that the material of the cutting tool that is used in the machining process KK8 is changed in accordance with the message MSG designated as number 6 shown on the display 6 to increase the cutting speed of the cutting tool. In the machining program PRO, the cutting speed upper-limit value is increased in the machining process KK8 and the cutting speed can be increased as long as it does not exceed the upper-limit value. This permits faster and efficient machining.

[0038]

If the cutting speed determiner 42 determines that the cutting speed by the face mill is equal to or lower than the cutting speed upper-limit value WJ at step STP302, the rotating speed determiner 50 judges whether or not the rotating speed of the spindle by the face mill is equal to or lower than the base value CH, which is performed in the same manner as step STP303 (step STP305). At step STP305, the rotating speed determiner 50 determines that the rotating speed of the spindle is higher than the base value CH, it indicates that the spindle load cannot be increased (step STP301) but the cutting speed can be increased (step STP302). In such case, the output of the spindle is maintained at a constant value. Accordingly, the machining cannot be improved even if the cutting speed is increased. The sub-routine SR63 is thus terminated without showing a message, or the like. If the rotating speed determiner 50 determines that the rotating speed of the spindle is equal to or lower than the base value CH at step STP305, it indicates that the spindle load cannot be increased (step STP301) but the cutting speed can be increased (step STP302). In such case, the torque of the spindle is maintained at a constant value. The navigation

information manager 49 reads out the message MSG that corresponds to navigation information number 5 from the navigation information memory 47 and transmits the message MSG to the display controller 13. The display controller 13 then displays the received message MSG on the display 6 (step SPT306). The message MSG advises that the cutting speed can be increased to the cutting speed upper-limit value, as shown in Fig. 8. That is, in the machining process KK8, although the maximum spindle load is greater than the spindle load upper-limit value SF (within the range between 80% and 100%, for example), the cutting speed is equal to or lower than the cutting speed upper-limit value WJ and the rotating speed of the spindle is equal to or lower than the base value CH. Accordingly, if the cutting speed is increased as long as the spindle load does not exceed the original spindle load percentage, faster machining is performed. The message MSG designated as number 5 advises on the display 6 that the cutting speed is increased to the cutting speed upper-limit value, as shown in Fig. 8. The sub-routine SR63 is terminated after executing step STP306. When the machining program GPR is improved, which is described later, the machining condition is changed such that the cutting speed in the machining process KK8 is increased to the cutting speed upper-limit value WJ in accordance with the message MSG designated as number 5 shown on the display 6. In the machining program PRO, the cutting speed is increased in the machining process KK8. This permits faster and efficient machining.

[0039]

When it is determined that the maximum spindle load by the face mill is equal to or lower than the spindle load upper-limit value SF, the maximum spindle load is equal to or lower than the value of 80%. The cutting speed determiner 42 judges the cutting speed, which is performed in the same manner as step STP302 (step STP307). When the cutting speed

determiner 42 determines that the cutting speed is higher than the cutting speed upper-limit value WJ at step STP307, the rotating speed determiner 50 judges whether or not the rotating speed of the spindle by the face mill is equal to or lower than the base value CH (step STP308), which is performed in the same manner as steps STP303 and STP305. At step STP308, if the rotating speed determiner 50 determines that the rotating speed of the spindle is higher than the base value CH, which indicates that the spindle load can be increased (step STP301) but the cutting speed cannot be increased (step STP307). In such case, the output of the spindle is maintained at a constant value. The machining cannot be improved even if the cutting speed and the spindle rotating speed are increased. The sub-routine SR63 is terminated without showing a message, or the like. At step STP308, the rotating speed determiner 50 determines that the rotating speed of the spindle is equal to or lower than the base value CH, it indicates that the spindle load can be increased (step STP301), but the cutting speed cannot be increased (step STP307). In such case, the torque of the spindle is maintained at a constant value. The navigation information manager 49 reads out the message MSG that corresponds to navigation information number 7 from the navigation information memory 47 and transmits the message MSG to the display controller 13. The display controller 13 then displays the received message MSG on the display 6 (step SPT309). The message MSG advises that the diameter of the cutting tool is decreased to increase the rotating speed of the cutting tool. Accordingly, the rotating speed of the spindle is increased without increasing the cutting speed of the cutting tool to further increase the spindle load. That is, in the machining process KK8, although the maximum spindle load is equal to or lower than the spindle load upper-limit value SF, the cutting speed is higher than the cutting speed upper-limit value WJ and the rotating speed of

the spindle is equal to or lower than the base value CH. The cutting tool is changed to a tool having a smaller diameter such that the rotating speed of the spindle is increased above the base value CH without increasing the cutting speed of the cutting tool, which performs faster machining. The message MSG designated as number 7 advises on the display 6 that the diameter of the cutting tool is decreased to increase the cutting speed, as shown in Fig. 8. The sub-routine SR63 is terminated after executing step STP309. When the machining program GPR is improved, which is described later, the machining condition is changed such that the cutting tool used in the machining process KK8 is changed to a tool having a smaller diameter and the rotating speed of the spindle is increased above the base value CH in accordance with the message MSG designated as number 7 shown on the display 6. In the machining program PRO, the rotating speed of the spindle is increased without increasing the cutting speed, which increases the spindle load in the machining process KK8. This permits faster and efficient machining.

[0040]

When the cutting speed determiner 42 determines that the cutting speed by the face mill is equal to or lower than the cutting speed upper-limit value WJ at step STP307, it indicates that the spindle load and the cutting speed can be increased (step STP201). The navigation information manager 49 reads out the message MSG that corresponds to navigation information number 5 from the navigation information memory 47 and transmits the message MSG to the display controller 13. The display controller 13 then displays the received message MSG on the display 6 (step SPT310). The message MSG advises that the cutting speed can be increased to the cutting speed upper-limit value, as shown in Fig. 8. That is, in the machining process KK8, the maximum spindle load is equal to or lower than the spindle load upper-limit value SF, and the

cutting speed is equal to or lower than the cutting speed upper-limit value WJ. If the cutting speed is increased as long as the spindle load does not exceed the original spindle load percentage, faster machining is performed. The message MSG designated as number 5 advises on the display 6 that the cutting speed is increased to the cutting speed upper-limit value WJ, as shown in Fig. 8. The sub-routine SR63 is terminated after executing step STP310. When the machining program GPR is improved, which is described later, the machining condition is changed such that the cutting speed is increased as long as it does not exceed the cutting speed upper-limit value WJ in the machining process KK8 in accordance with the message MSG designated as number 5 shown on the display 6. In the machining program PRO, the cutting speed is increased in the machining process KK8. This permits faster and efficient machining.

[0041]

Step STP8 is performed, as shown in Fig. 3, after completion of the sub-routine SR63. At step STP8, the processing completion determiner 25 judges whether or not the ordinal variable i stored in the variable memory 20 has reached a maximum value (four, in this case), which is shown in Fig. 2(b). If the processing completion determiner 25 determines that the ordinal variable i is three and has not reached four, step STP9 is performed. In step STP9, the machining navigator 15 adds one to the variable i in an incremental manner. Thus, the variable i becomes four. Afterward, the processing returns to step STP5, as shown in Fig. 3. The machining navigator 15 commands the sub-routine number selector 21 to select the number of a sub-routine. The sub-routine number selector 21 commands the subject tool determiner 27 to determine the type of the cutting tool that is the subject of the fourth machining process. The subject cutting tool is an end mill used for finish machining, for example. Subsequently, the selection of the sub-routine

number assigned to the determined tool type is carried out referring to the sub-routine number table VTB. In this case, the sub-routine number is 64, as shown in Fig. 2(c). At that time, the subject tool determiner 27 stores the tool number T10 corresponding to the variable i in the variable memory 20, which is the number of the subject tool in the fourth process, in the subject tool number memory 29.

[0042]

The sub-routine number determiner 23 determines whether or not the sub-routine number selector 21 has selected a sub-routine number (step STP6) and outputs a selection completion signal S2. When the selection completion signal S2 is output, the machining navigator 15 executes the sub-routine SR64 (shown in Fig. 7) that has the selected sub-routine number (64) (step STP7). In the sub-routine SR64, the machining navigator 15 commands the cutting speed determiner 42 to determine the cutting speed (step STP401).

[0043]

The process in step STP401 is the same as that of step STP302 in the sub-routine SR63. At step STP401, the cutting speed determiner 42 determines the cutting speed by the end mill based on the tool number T10, which is stored in the subject tool number memory 29, and the machining state information HJ, which is stored in the simulation result information memory 12a. In this case, the cutting speed is 80.0 m/min. The cutting speed upper-limit value calculator 46 refers to the machining program GPR stored in the machining program memory 10 to determine the material of the subject workpiece. The calculator 46 also refers to the cutting tool data file KDF in the cutting tool data memory 9 to determine the material of the end mill based on the tool number T10, which is stored in the subject tool number memory 29. Afterward, the calculator 46 selects the basic cutting speed upper-limit value that corresponds to the material of the workpiece from the basic cutting speed upper-limit file SYF2,

which is stored in the basic cutting speed upper-limit file memory 43. The calculator 46 further selects the cutting speed upper-limit coefficient that corresponds to the selected tool material based on the tool material and the cutting speed upper-limit coefficient file SKF2, which is stored in the upper-limit cutting speed coefficient file memory 45. The calculator 46 then multiplies the selected basic cutting speed upper-limit value with the selected cutting speed upper-limit coefficient to obtain the cutting speed upper-limit value WJ (m/min). Accordingly, the material of the cutting tool used for machining and the material of the subject workpiece are taken into consideration when computing the limit value WJ.

[0044]

The cutting speed determiner 42 judges that the cutting speed of the end mill that is used for finish machining is higher than the cutting speed upper-limit value WJ, it indicates that the cutting speed exceeds the cutting speed upper-limit value WJ when the machining is performed using the cutting tool that is selected in the machining program GPR. Thus, a signal indicating the type of the cutting tool used in the fourth machining process (end mill used for finish machining, in this case), which is determined by the subject cutting tool determiner 27, is output to the navigation information manager 49. In such a case, the navigation information manager 49 reads out the message MSG that corresponds to navigation information number 9 from the navigation information memory 47 and transmits the message MSG to the display controller 13. The display controller 13 then displays the received message MSG on the display 6 (step STP402). As shown in Fig. 8, the message MSG advises the operator to change the material of the cutting tool such that the cutting speed is increased and to use a cutting tool that has a larger number of teeth such that the cutting feed rate may be increased. Specifically, the cutting speed is higher

than the cutting speed upper-limit value WJ in the machining process KK10. The material of the cutting tool is changed to increase the cutting speed upper-limit value WJ, which increases the cutting speed of the cutting tool. Also, the cutting tool is changed to one having a larger number of teeth to increase the cutting feed rate. The message MSG designated as number 9 advises on the display 6 that the cutting tool is changed to one having a larger number of teeth to increase the cutting feed rate and the material of the cutting tool is changed to increase the cutting speed, as shown in Fig. 8. For example, if the material of the cutting tool designated in the machining program GPR is HSS, the cutting speed upper-limit coefficient of which is 25%, as shown in Fig. 9(d), the message advises that the material is changed to carbide, the cutting speed upper-limit coefficient of which is 100%, as shown in Fig. 9(d). The sub-routine SR64 is terminated after executing step STP402. When the machining program GPR is improved, which is described later, the machining condition is changed such that the material of the cutting tool that is used in the machining process KK10 is changed and the cutting tool that is used in the machining process KK10 is changed to one having a larger number of teeth in accordance with the message MSG designated as number 9 shown on the display 6 such that the cutting speed is increased as long as it does not exceed the cutting speed upper-limit value WJ, and the cutting feed rate is increased. In the machining program PRO, the cutting speed and the cutting feed rate are increased in the machining process KK10. This permits faster and efficient machining.

[0045]

If the cutting tool that is the subject cutting tool in the forth machining process is a face mill used for finish machining (the sub-routine SR64 is common to both a end mill and face mill for finish machining), the same process is performed in step STP401 as that described above. Afterward,

at step STP402, the navigation information manager 49 reads out the message MSG that corresponds to navigation information number 10 from the navigation information memory 47 and transmits the message MSG to the display controller 13. The display controller 13 then displays the received message MSG on the display 6. The cutting speed is higher than the cutting speed upper-limit value WJ in the machining process KK10. Thus, the cutting tool is changed to one having a larger number of teeth to increase the cutting feed rate and the material of the cutting tool is changed to increase the cutting speed upper-limit value WJ such that the cutting speed of the cutting tool is increased. This permits faster machining. As shown in Fig. 8, the message MSG advises the operator to change the cutting tool to one having a larger number of teeth such that the cutting feed rate is increased and change the material of the cutting tool such that the cutting speed is increased. Specifically, if the material of the cutting tool is carbide, the cutting speed upper-limit coefficient of which is 100%, as shown in Fig. 9(f), the message advises to change the material to coated carbide, the cutting speed upper-limit coefficient of which is 115%, as shown in Fig. 9(f) or cermet, the cutting speed upper-limit coefficient of which is 120%, as shown in Fig. 9(f). The machining program GPR is improved in accordance with the message, which permits faster and efficient machining.
[0046]

When the cutting speed determiner 42 determines that the cutting speed by the end mill (or face mill) is equal to or lower than the cutting speed upper-limit value WJ at step STP401, it indicates that the cutting speed of the cutting tool selected in the machining program GPR can be increased. The navigation information manager 49 reads out the message MSG that corresponds to navigation information number 8 from the navigation information memory 47 and transmits the message MSG to the display controller 13. The display

controller 13 then displays the received message MSG on the display 6 (step STP403). The message MSG advises that the cutting speed can be increased to the cutting speed upper-limit value, as shown in Fig. 8. That is, in the machining process KK10, the cutting speed is equal to or lower than the cutting speed upper-limit value WJ. If the cutting speed is increased in accordance with an increase in the cutting speed upper-limit value WJ, the faster machining is performed. The message MSG designated as number 8 advises on the display 6 that the cutting speed is increased to the cutting speed upper-limit value WJ, as shown in Fig. 8. After executing step STP403, the sub-routine SR64 is terminated. In such case, when the machining program GPR is improved, which is described later, the machining condition is changed such that the cutting speed is increased as long as it does not exceed the cutting speed upper-limit value WJ in the machining process KK10 in accordance with the message MSG designated as number 8 shown on the display 6. In the machining program PRO, the cutting speed is increased in the machining process KK10. This permits faster and efficient machining.

[0047]

After the sub-routine SR64 is completed, the machining navigation proceeds to step STP8, as shown in Fig. 3. At step STP8, the processing completion determiner 25 judges whether or not the ordinal variable i stored in the variable memory 20 has reached a maximum value (four in this case), which is shown in Fig. 2(b). If the processing completion determiner 25 determines that the ordinal variable i is four and has reached four, the navigation program NPR is completed. As described above, when obtaining the navigation information (e.g. MSG, which is shown in Fig. 8) relating to the machining processes KK2, KK5, KK8, and KK10 that are performed with tools having tool number T2, T5, T8, and T10, respectively, the operator changes, for example, the material or cutting speed of the cutting tool, or rotating speed of

the spindle in accordance with the messages in each machining process, which improves the machining program GPR with a known programming method. Accordingly, the machining program PRO is made by improving a part of the machining program GPR. The machining program PRO is stored in the machining program memory 10 instead of the machining program GPR.

[0048]

The machining program PRO is improved so that machining is performed at the highest speed allowed by the capacity of the spindle motor, or the like. Therefore, high speed and efficient machining is performed by using the machining program PRO in comparison to when using the uncorrected machining program GPR. Furthermore, the operator designates the machining process, which needs to be improved, in the machining program GPR, which is made using an automatic programming method. Specific information, or the message MSG, is displayed for improving the machining process. Accordingly, the operator easily produces the machining program PRO, which permits high speed machining, by improving the machining program GPR in accordance with the information shown by the machining navigation apparatus 2 of this embodiment. Furthermore, the machining navigation apparatus 2 facilitates the correction of machining programs made for conventional machining tools to adapt to new machining tools having increased spindle capacities or using new types of tools. Therefore, machining programs are always adapted to updated machining tools by the machining navigation apparatus 2. Since the obsolescence of programs is avoided, software is used continuously and efficiently.

[0049]

The machining navigation apparatus 2 according to the present invention, which is an example of the programming aiding apparatus for machining programs, is employed to aid the composition of a machining program PRO in a machining center 2. However, the present invention may also be applied

to other types of machine tools, such as a lathe, an electric discharge machine, and a laser cutting machine to aid the composition of machining programs (corrected machining program). In such cases, the machining conditions and the machining state variables including machining state information HJ (maximum spindle load, the cutting speed of the cutting tool, and the spindle rotating speed, shown in Fig. 2(d)) of this embodiment are changed in accordance with the type of machine (the spindle rotating speed, the spindle load, the distance between electrodes and the voltage load, for example). Furthermore, the parameters that are referred to judge the machining efficiency, that is, the spindle load upper-limit value SF, the cutting speed upper-limit value WJ, and the spindle speed base value CH, are changed to parameters corresponding to the machine (the spindle load upper-limit value and a voltage load upper-limit value, for example). The messages that appear on the display may also be changed in accordance with the machine.

[0050]

The machining navigation apparatus 2 of this embodiment, which is an example of a programming aiding apparatus for machining programs, is incorporated in the control unit 100 of the machining center 2. However, the programming aiding apparatus may be an apparatus that is independent from the machining center 2 or the control unit 100. Furthermore, the machining simulation (or actual machining) may be executed by an apparatus separate from the machining navigation apparatus. In this case, among the simulation result information KJ, only the values of machining state information HJ (machining state variables) of the machining processes, the machining conditions of which should be corrected, is transmitted to the programming aiding apparatus to execute an analysis (machining navigation) on those processes. Accordingly, the programming aiding apparatus need not store original machining programs GPR. Thus, the machining program memory 10

is not necessary.

[0051]

In the above illustrated embodiment, when the messages MSG of Fig. 8 appear on the display 6, the message MSG explains, for example, that the cutting speed may be increased to the cutting speed upper-limit value. In this case, however, the message MSG may explain that the cutting speed may be increased to a specific value, which corresponds to the limit value. For example, the message MSG may explain that the cutting speed may be increased to (value) m/min. Furthermore, specific examples showing how to perform high speed machining may be shown on the display 6. For example, the type of cutting tool may be shown together on the display 6 with the machining conditions, such as the cutting speed and the feed rate.

[0052]

In the above illustrated embodiment, machining navigation is performed once for each subject machining process (that is, the processes such as the sub-routines SR61 to SR64 are performed once, respectively). However, machining navigation may be performed twice or more for each machining process (that is, the processes such as the sub-routines SR61 to SR64 may be performed twice or more, respectively). For example, after the machining program is improved by performing the navigation program NPR, the machining simulation may be performed again. The navigation program NPR may be performed again in accordance with the result of the simulation such that the machining program is improved. The sequence of processes including the performance of the machining simulation (or the performance of the test machining), the performance of the navigation program NPR, and the improvement of the machining program may be repeated such that a better machining program is produced. Even if the navigation program NPR shown in Fig. 3 is not adapted and the subject machining processes for the machining navigation may

be input one after another to perform the machining navigation, which has been described, the sequence of processes including the performance of the machining simulation (or the performance of the test machining), the performance of the machining navigation, and the improvement of the machining program may be repeated such that a better machining program is produced.

[0053]

In the illustrated embodiment, the parameters used to judge the machining efficiency are the spindle load upper-limit value SF, the cutting speed upper-limit value WJ, and the spindle speed base value CH. However, any parameter can be used as long as the machining efficiency can be judged. For example, in addition to base value CH, the output characteristics relative to the spindle rotating speed may be used as a parameter related with the spindle rotating speed. More specifically, as shown in the graph of Fig. 10, the machining navigation apparatus 2 may store characteristic data QG that shows the relationship between the spindle rotating speed and the spindle output. In this case, during execution of the machining navigation, the machining efficiency is judged from the spindle speed in accordance with the spindle characteristic data QG. As shown in Fig. 10, if the spindle rotating speed is lower than a rotating speed ch1 corresponding to the base value CH, the spindle rotating speed is included in range P1 where the spindle torque remains fixed, and the output of the spindle may be increased to the maximum output. When the spindle rotating speed is included in range P1, it may be judged that the machining efficiency is improved, for example, by increasing the spindle rotating speed. If the spindle rotating speed is equal to or higher than the rotating speed ch1, the spindle rotating speed is included in range P2 where the spindle output remains fixed at a constant maximum value regardless of changes in the spindle rotating speed. When the spindle

rotating speed is included in range P2, it is judged that the machining efficiency is not improved by increasing the spindle rotating speed. The machining efficiency is judged to be improved based on the spindle characteristic data QG when the spindle rotating speed is included in range P3, which is shown in the chain double-dashed line in Fig. 10. In range P3, when the rotating speed exceeds a rotating speed ch2, which is higher than the base rotating speed ch1, the output decreases as the rotating speed increases. As shown in Fig. 10, for example, when the spindle rotating speed is higher than the predetermined rotating speed ch2, the machining is performed in range P3. It may be judged that the machining efficiency is improved, for example, if the spindle rotating speed is decreased to a value lower than the rotating speed ch2 (and more than the rotating speed ch1).

[0054]

In the illustrated embodiment, after the machining navigation is executed, the operator (or programmer) refers to the displayed message to improve the machining program. However, owing to the technical progress of peripheral equipment (i.e., the tool management system, abnormality management system, sensors), machine tools such as the machining center 1 may automatically improve machining programs (that is, machining tools may upgrade machining conditions). Furthermore, in the illustrated embodiment, the message MSG in the machining navigation is displayed as words (sentences). However, characters, diagrams, images, and voices may be used for the message as long as advice for changing the machining conditions is given.

[0055]

[Effects of the Invention]

As described above, the first invention of the present invention provides the programming aiding apparatus for a machining program that aids an operator to produce an improved machining program such as the machining program PRO

by correcting an original machining program such as the machining program GPR. The original machining program includes at least one machining process such as the machining processes KK1 to KK10 where a machining condition is set. The original machining program is improved with reference to machining state variables such as the machining state information HJ relating to the machining process. The machining state variables are obtained by executing the original program. The apparatus includes a message storing section such as the navigation information memory 47, a machining state variable memory such as the simulation result information memory 12a, a first memory means such as the system program memory 16, a machining state variable analyzing section such as the spindle load judging section 41, cutting speed judging section 42, and rotating speed judging section 50, and a message displaying section such as the display 6 and the display controller 13. The message storing section stores a message such as the messages MSG that shows an advice for improving the machining condition of the machining process. The machining state variable memory stores the machining state variables of the machining process that is obtained by executing the original machining program. The first memory means stores a machining efficiency judging program such as the sub-routines SR61 to SR64. The machining efficiency judging program judges the machining efficiency of each machining process based on machining efficiency judging parameters such as the spindle load upper-limit value SF, cutting speed upper-limit value WJ, base rotating speed CH, and spindle characteristic data QG. The machining state variable analyzing section analyzes the machining state variables of the machining process in the original machining program based on the machining efficiency judging program that is stored in the first memory means. The message displaying section selects and displays messages stored in the message storing section in accordance with the result of

the analysis performed by the machining state variable analyzing section. Therefore, the programming aiding apparatus for machining programs of this invention analyzes the machining state variables of the machining process, which needs to be improved, in the original machining program such as a machining program that is made using an automatic programming method (or a machining program in the process of programming) and a programmed machining program, based on the machining efficiency judging program, and shows the advice by displaying the messages to improve the machining program in accordance with the result of the analyses. Accordingly, the operator easily composes the corrected machining program, which permits efficient machining (that is, high speed machining) by improving the machining conditions of the original machining program without any specific knowledge and experience in accordance with the advice shown by the programming aiding apparatus of machining programs. Furthermore, the present invention facilitates the correction of original machining programs made for conventional machining tools to adapt to new machining tools having increased spindle capacities or new types of materials for cutting tools. Therefore, machining programs are always adapted to updated machining tools. Since the obsolescence of programs is avoided, software is used continuously and efficiently.

[0056]

The second invention of the present invention provides the apparatus according to the first invention further comprising a machining process designating means such as the keyboard 5 for designating the machining process that is the subject of the analysis performed by the machining state variable analyzing section. The machining state variable analyzing section analyzes the machining state variables of the machining process designated by the machining process designating means based on the machining efficiency judging

program stored in the first memory means. That is, the analyses by the machining state variable analyzing section are not performed for all machining processes in the original machining program. If the operator designates the machining process, the machining efficiency of which the operator wishes to improve, the analyses are performed by the machining state variable analyzing section only for the designated machining processes. Therefore, the second invention obtains the effects that the processing time is saved in addition to the effects of the first invention.

[0057]

The third invention of the present invention provides the apparatus according to the first invention further comprising a second memory means for storing the original machining program and a machining simulation means for performing machining simulation based on the original machining program stored in the second memory means. The machining state variable memory stores the computed values obtained by performing machining simulation by the machining simulation means with the machining state variables. The machining state variables are obtained by performing machining simulation without performing actual machining. Therefore, the second invention obtains the effect that time or labor is saved in addition to the effects of the first invention.

[0058]

The fourth invention of the present invention provides the apparatus according to the first invention, wherein the machining state variables include the load applied to a spindle of a machine and the machining efficiency judging parameter relates to the spindle load. The machining state variable analyzing section analyzes the machining state variables relating to the spindle load in the machining process of the original machining program based on the machining efficiency judging parameter relating to the

spindle load. That is, the machining efficiency is judged based on the spindle load. The message advises to improve the machining condition by effectively increasing the spindle load within the capacity of the cutting machine. Therefore, the fourth invention obtains the effect that the machining efficiency is accurately improved by increasing the spindle load such that programming of the machining programs is appropriately supported, in addition to the effects of the first invention.

[0058]

The fifth invention of the present invention provides the apparatus according to the first invention, wherein the machining state variables include the cutting speed of a cutting tool, and the machining efficiency judging parameter relates to the cutting speed of the cutting tool. The machining state variable analyzing section analyzes the machining state variables relating to the cutting speed of the cutting tool in the machining process of the original machining program based on the machining efficiency judging parameter relating to the cutting speed of the cutting tool. That is, the machining efficiency is judged based on the cutting speed of the cutting tool. The message advises to improve the machining condition by effectively increasing the cutting speed of the cutting tool. Therefore, the fifth invention obtains the effect that the machining efficiency is accurately improved by increasing the cutting speed such that programming of the machining programs is appropriately supported, in addition to the effects of the first invention.

[0060]

The sixth invention of the present invention provides the apparatus according to the first invention, wherein the machining state variables include the rotating speed of a spindle of a machine, and wherein the machining efficiency judging parameter relates to the spindle rotating speed. The machining state variable analyzing section analyzes the

machining state variables relating to the spindle rotating speed in the machining process of the original machining program based on the machining efficiency judging parameter relating to the spindle rotating speed. That is, the machining efficiency is judged based on the spindle rotating speed. The message advises to improve the machining condition by effectively increasing the spindle rotating speed. The sixth invention obtains the effect that the machining efficiency is accurately improved by increasing the spindle rotating speed such that programming of the machining programs is appropriately supported, in addition to the effects of the first invention.

[0061]

The seventh invention of the present invention provides the apparatus according to the first invention, wherein the message storing section stores the message that advises to increase the cutting speed of a cutting tool such that the machining condition is improved. Therefore, the seventh invention obtains the effect that the machining efficiency is improved by effectively increasing the cutting speed of the cutting tool such that programming of the machining programs is appropriately supported, in addition to the effects of the first invention.

[0062]

The eighth invention of the present invention provides the apparatus according to the first invention, wherein the message storing section stores the message that advises to increase the rotating speed of a spindle such that the machining condition is improved. Therefore, the eighth invention obtains the effect that the machining efficiency is improved by effectively increasing the spindle rotating speed such that programming of the machining programs is appropriately supported, in addition to the effects of the first invention.

[0063]

The ninth invention of the present invention provides the apparatus according to the first invention, wherein the message storing section stores the message that advises to change a cutting tool such that the machining condition is improved. Therefore, the ninth invention obtains the effect that the machining efficiency is improved by changing the cutting tool to further increase the cutting speed of the cutting tool or the spindle rotating speed such that programming of the machining programs is appropriately supported, in addition to the effects of the first invention.

[Brief Description of the Drawings]

[Fig. 1] A block diagram showing a control apparatus for a machining center having a navigation apparatus as a programming aiding apparatus according to the present invention.

[Fig. 2] Fig. 2(a) is a graph showing machining timing data;

Fig. 2(b) is a table showing the processing procedures;

Fig. 2(c) is a diagram showing sub-routine numbers;

Fig. 2(d) is a diagram showing machining state information.

[Fig. 3] A flowchart showing the contents of a navigation program.

[Fig. 4] A flowchart showing the contents of a sub-routine 61R.

[Fig. 5] A flowchart showing the contents of a sub-routine 62R.

[Fig. 6] A flowchart showing the contents of a sub-routine 63R.

[Fig. 7] A flowchart showing the contents of a sub-routine 64R.

[Fig. 8] A diagram showing a navigation data file.

[Fig. 9] Fig. 9 (a) is a diagram showing a basic cutting speed upper-limit file SYF1;

Fig. 9(b) is a diagram showing a cutting speed upper-limit coefficient file SKF1;

Fig. 9(c) is diagram showing a basic cutting speed upper-

limit file SYF2;

Fig. 9(d) is a diagram showing a cutting speed upper-limit coefficient file SKF2;

Fig. 9(e) is diagram showing a basic cutting speed upper-limit file SYF3; and

Fig. 9(f) is a diagram showing a cutting speed upper-limit coefficient file SKF3.

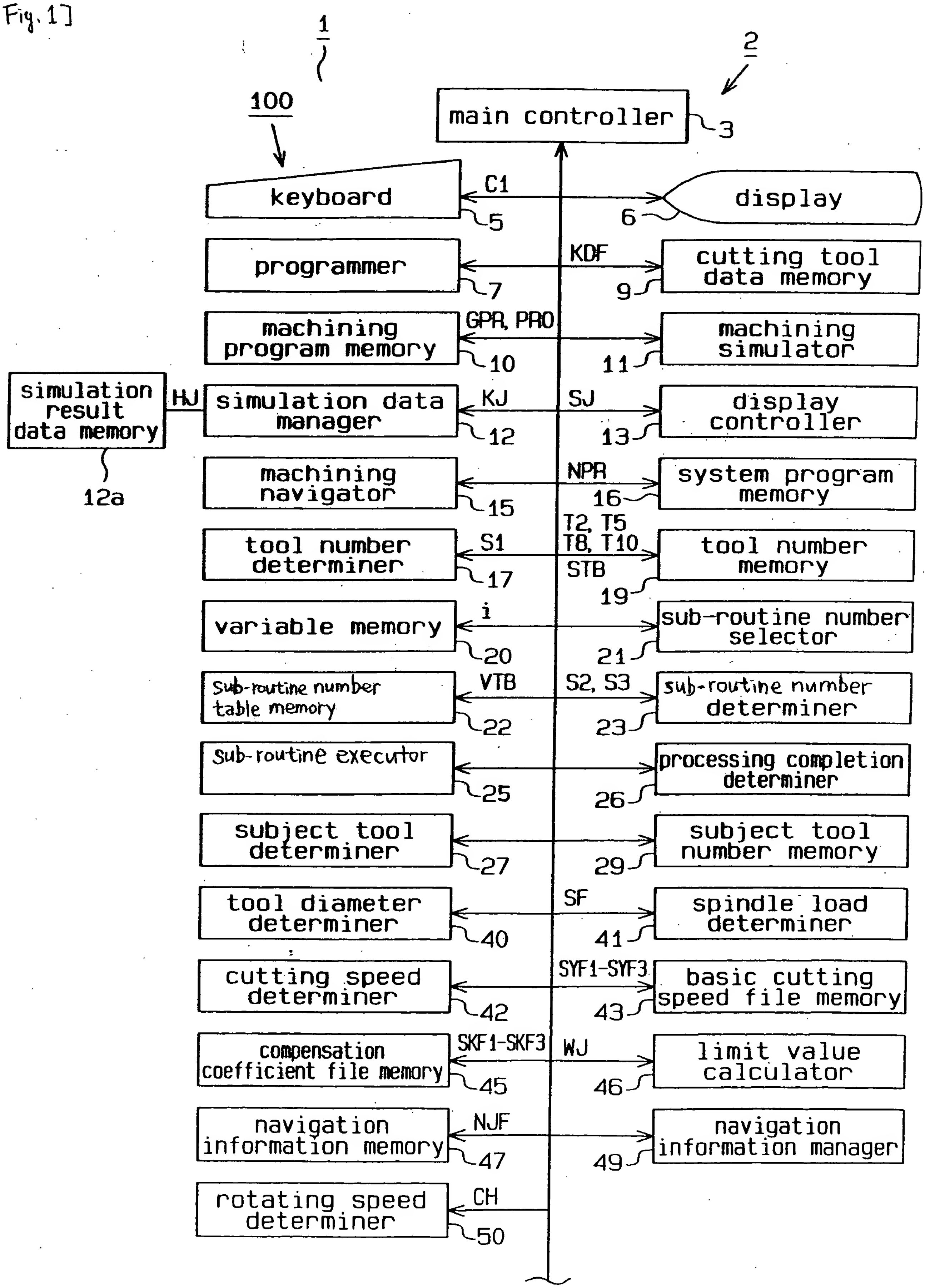
[Fig. 10] A graph showing the output characteristics of the spindle relative to the rotating speed.

[Description of the Numerals]

2······programming aiding apparatus for machining programs (machining navigation apparatus), 5······machining process designating means (keyboard), 6······message display section (display), 10······second memory means (machining program memory), 11······machining simulation means (machining simulator), 12a······machining state variable memory (simulation result information memory), 13······message display section (display controller), 16······first memory means (system program memory), 41······machining state variable analyzing section (spindle load determiner), 42······machining state variable analyzing section (cutting speed determiner), 47······message storing section (navigation information memory), 50······machining state variable analyzing section (rotating speed determiner), CH······machining efficiency judging parameter (base rotating speed), GPR······original machining program (machining program), HJ······machining state variable (machining state information), MSG······message, PRO······corrected machining program (machining program), QG······machining efficiency judging parameter (spindle characteristic data), SF······machining efficiency judging parameter (spindle load upper-limit value), WJ······machining efficiency judging parameter (cutting speed upper-limit value), KK1 to KK10······machining process, SR61 to SR64······machining efficiency judging program (sub-routine).

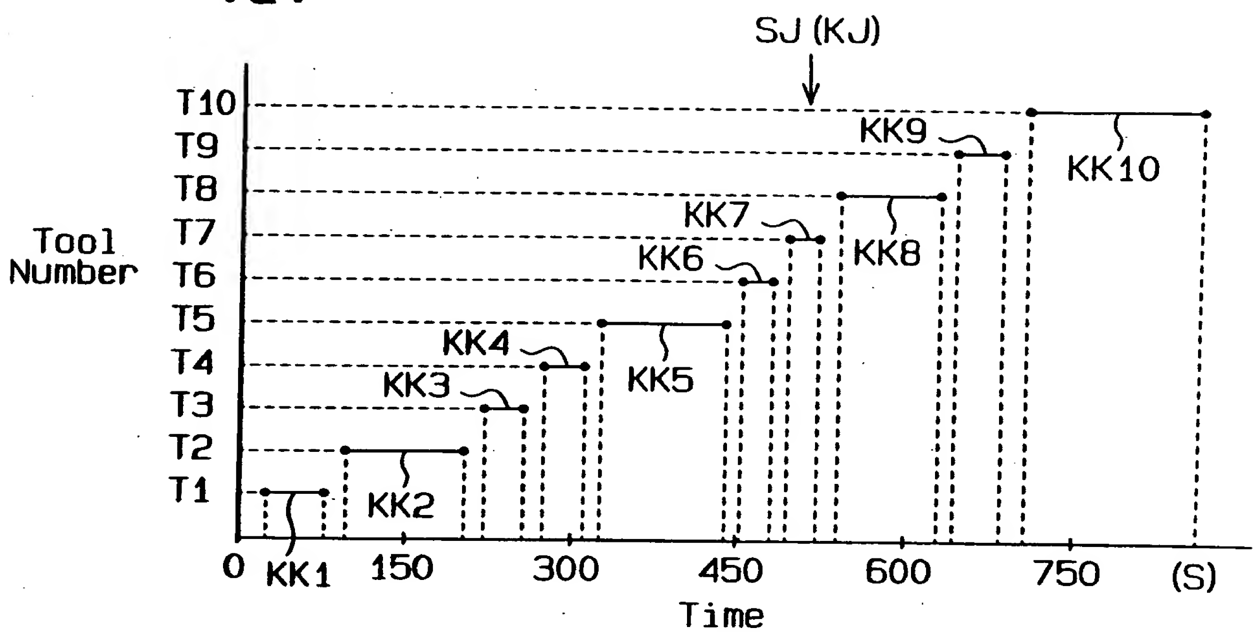
[Title of Document] Drawings

[Fig. 1]



[Fig.2]

(a)



(b)

STB

Ordinal Number (i)	1	2	3	4
Tool Number	T2	T5	T8	T10

(c)

VTB

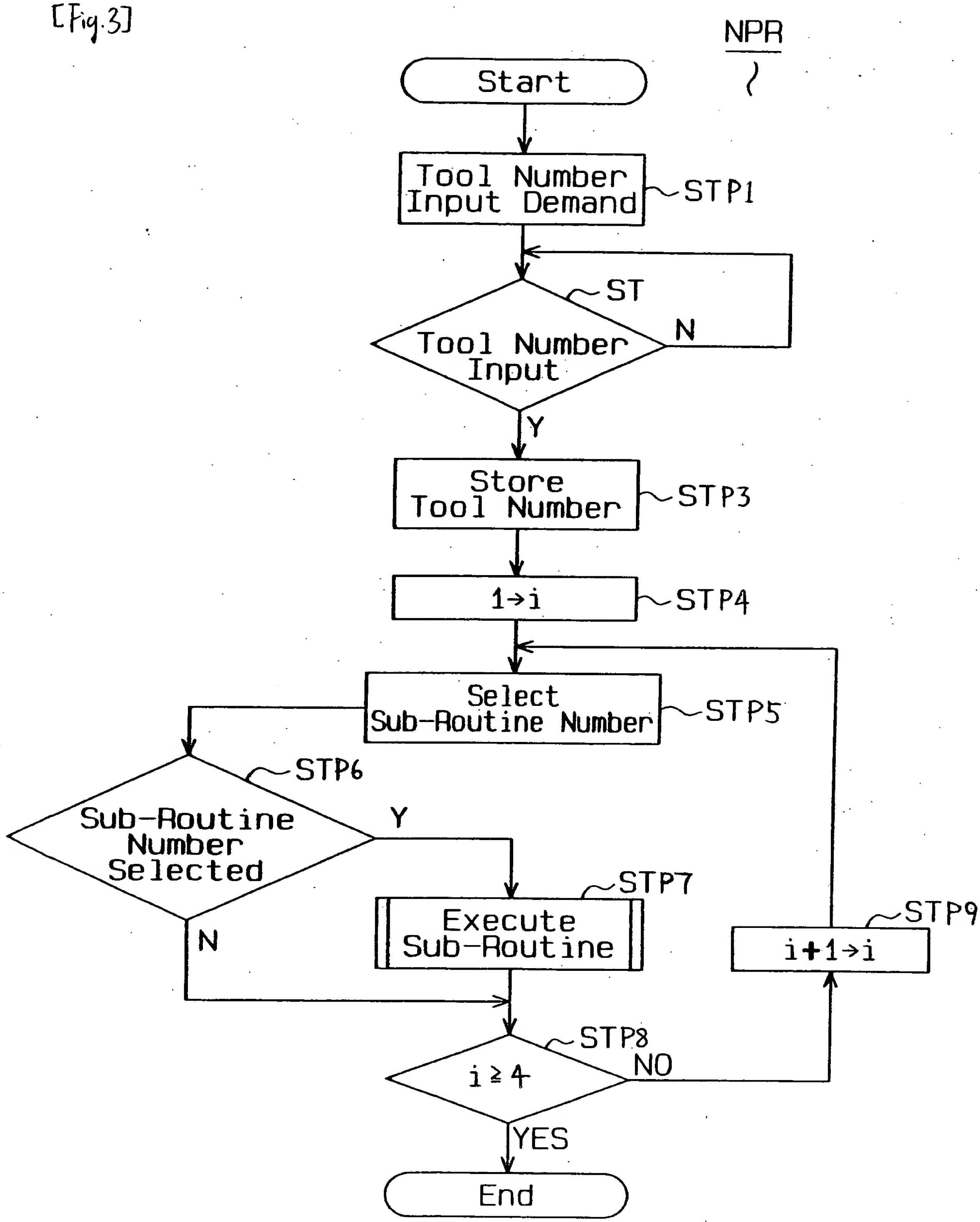
Tool Type	Drill	End Mill (Roughing)	Face Mill (Roughing)	End Mill (Finishing)	Face Mill (Finishing)
Sub-Routine Number	61	62	63	64	64

(d)

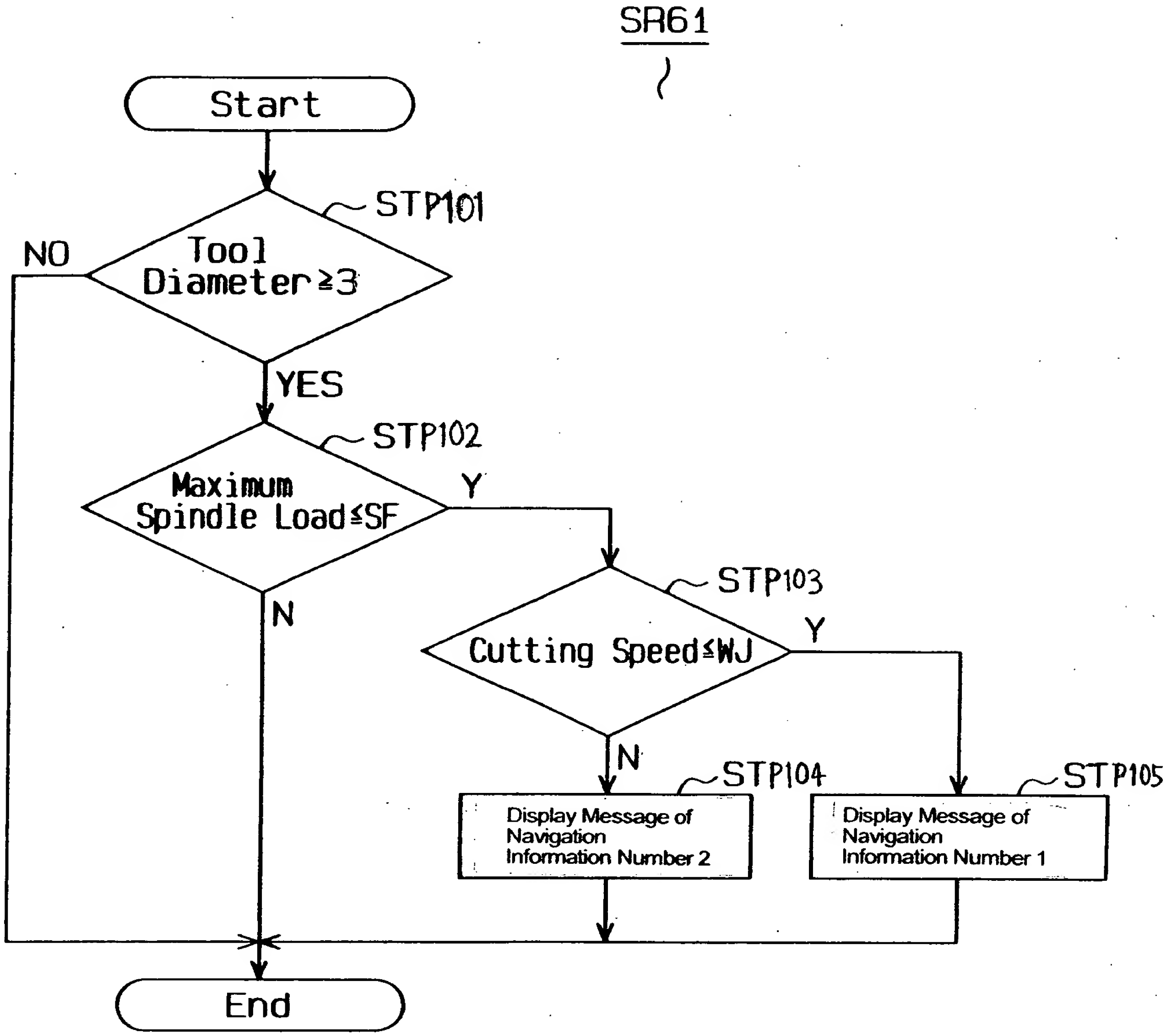
HJ (KJ)

Tool Number	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Maximum Spindle Load (%)	72	60	54	57	81	73	45	67	39	58
Cutting Speed (m/min)	45.9	40.8	124.0	87.5	100.4	72.1	53.4	110.9	120.0	80.0
Rotating Speed (min^{-1})	185	163	496	350	401	288	213	662	480	320

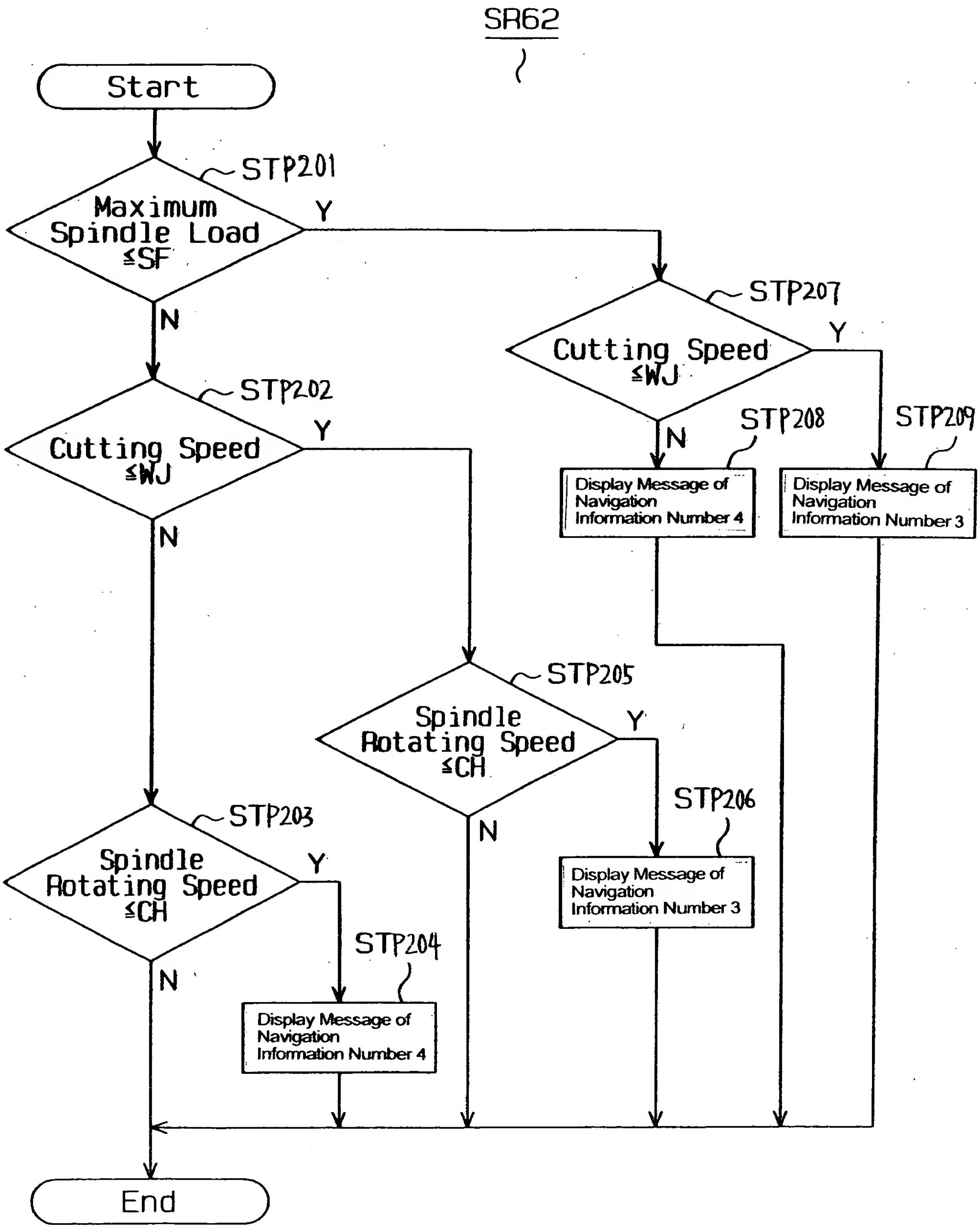
[Fig.3]


NPR
Start
Tool Number Input Demand
STP1
ST
Tool Number Input
N
Y
Store Tool Number
STP3
1→i
STP4
Select Sub-Routine Number
STP5
STP6
Sub-Routine Number Selected
Y
N
STP7
Execute Sub-Routine
STP9
i+1→i
STP8
i≥4
NO
YES
End

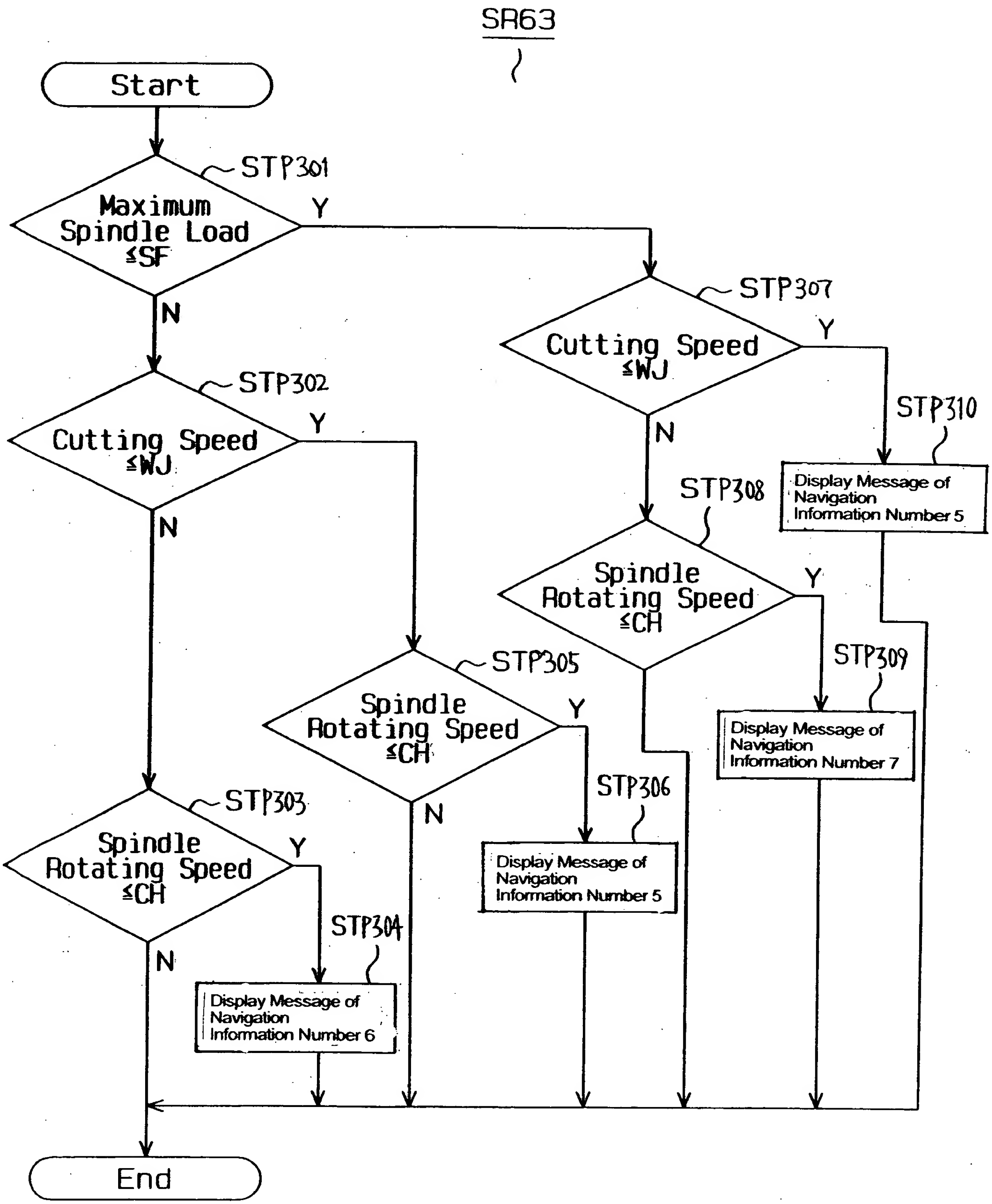
[Fig. 4]


SR61
Start
STP101
Tool
Diameter≥3
NO
YES
STP102
Maximum
Spindle Load≤SF
Y
N
STP103
Cutting Speed≤WJ
Y
N
STP104
Display Message of
Navigation
Information Number 2
STP105
Display Message of
Navigation
Information Number 1
End

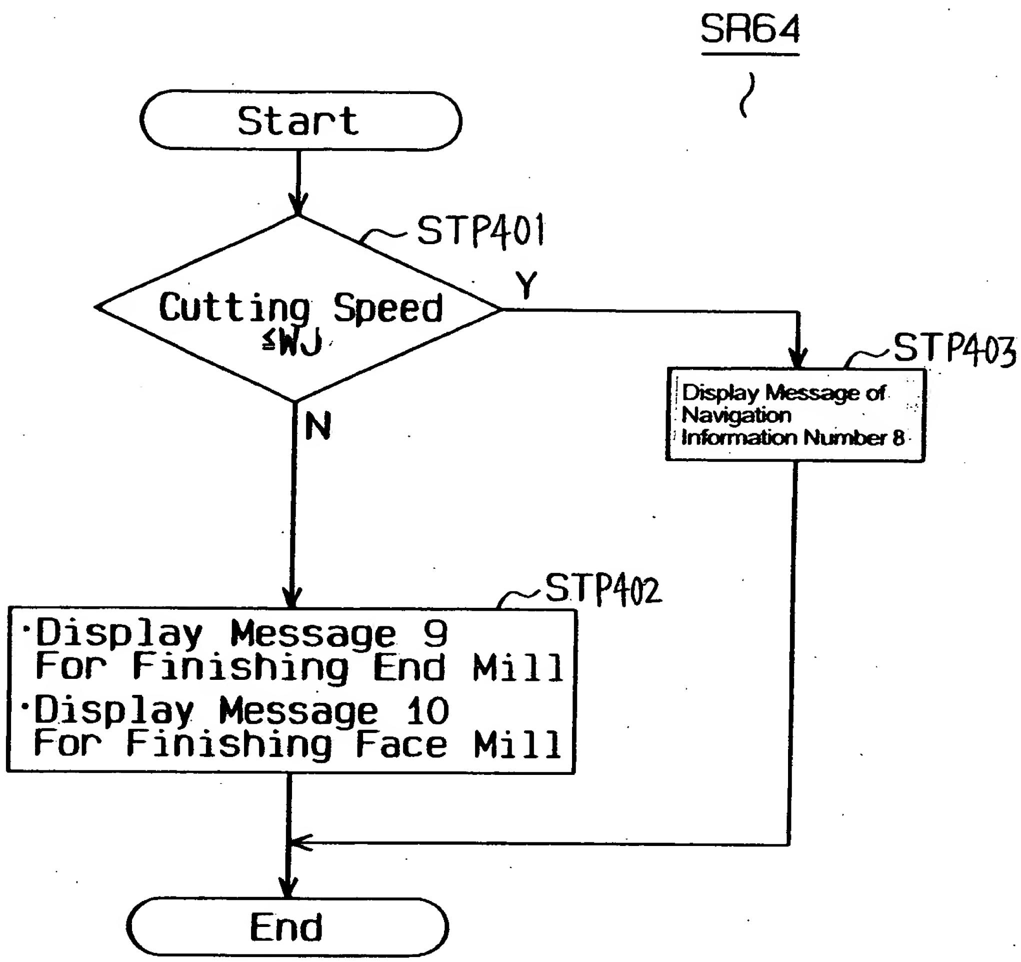
[Fig. 5]


SR62
Start
STP201
Maximum Spindle Load ≦SF
Y
N
STP207
Cutting Speed ≦WJ
Y
N
STP208
STP209
Display Message of Navigation Information Number 4
Display Message of Navigation Information Number 3
STP202
Cutting Speed ≦WJ
Y
N
STP205
Spindle Rotating Speed ≦CH
Y
N
STP206
Display Message of Navigation Information Number 3
STP203
Spindle Rotating Speed ≦CH
Y
N
STP204
Display Message of Navigation Information Number 4
End

[Fig. 6]


SR63
Start
STP301
Maximum Spindle Load ≤SF
Y
N
STP302
Cutting Speed ≤WJ
Y
N
STP303
Spindle Rotating Speed ≤CH
Y
N
STP304
Display Message of Navigation Information Number 6
STP305
Spindle Rotating Speed ≤CH
Y
N
STP306
Display Message of Navigation Information Number 5
STP307
Cutting Speed ≤WJ
Y
N
STP308
Spindle Rotating Speed ≤CH
Y
STP309
Display Message of Navigation Information Number 7
STP310
Display Message of Navigation Information Number 5
End

[Fig. 7]


SR64
Start
STP401
Cutting Speed ≦WJ
Y
N
STP403
Display Message of Navigation Information Number 8
STP402
·Display Message 9 For Finishing End Mill
·Display Message 10 For Finishing Face Mill
End

[Fig. 8]

NJF

Navigation Information Number	Message (MSG)
1	·Cutting speed can be increased to limit value
2	·Change cutting tool material and increase cutting speed Change HSS tool (small diameter) to carbide tool Change HSS tool (large diameter) to throw away tool Change carbide tool to coolant through tool (for spindle through machines) Change carbide tool to carbide coating tool (for non-spindle through machines)
3	·Cutting speed can be increased to limit value (fix cutting speed if cutting speed is equal to or higher than maximum spindle rotating speed)
4	·Change cutting tool material and increase cutting speed Change HSS tool (small diameter) to carbide tool Change HSS tool (large diameter) to throw away tool
5	·Cutting speed can be increased to limit value (fix cutting speed if cutting speed is equal to or higher than maximum spindle rotating speed)
6	·Change cutting tool material and increase cutting speed Change carbide tool to carbide coating tool (except when the workpiece material is AL)
7	·Decrease tool diameter and increase rotating speed
8	·Cutting speed can be increased to limit value (fix cutting speed if cutting speed is equal to or higher than maximum spindle rotating speed)
9	·Change to tool with a larger teeth number and increase feed rate ·Change cutting tool material and increase cutting speed Change HSS tool to carbide tool Change carbide tool to carbide coating tool (except when the workpiece material is AL)
10	·Change to tool with a larger teeth number and increase feed rate ·Change cutting tool material and increase cutting speed (except when workpiece material is AL) Change carbide tool to carbide coating tool or cermet tool Change carbide coating tool to cermet tool

[Fig. 9]

(a) SYF1

Workpiece Material	Basic Cutting Speed
FC	30
FCD	25
S45C	30
SCM	25
SUS	15
AL	75
CU	75
:	:

(b) SKF1

Tool Material	Compensation Coefficient
HSS	100
Carbide	220
HSS Coating	150
Coolant Through	460
Throw Away	560
Brazed	240
:	:
:	:

ta1
ta2
ta3

(c) SYF2

Workpiece Material	Basic Cutting Speed
FC	120
FCD	110
S45C	100
SCM	90
SUS	85
AL	700
CU	230
:	:

(d) SKF2

Tool Material	Compensation Coefficient
HSS	25
Carbide	100
HSS Coating	30
Carbide Coating	110
Roughing	40
Throw Away	150
:	:
:	:

td1
td2
td3

(e) SYF3

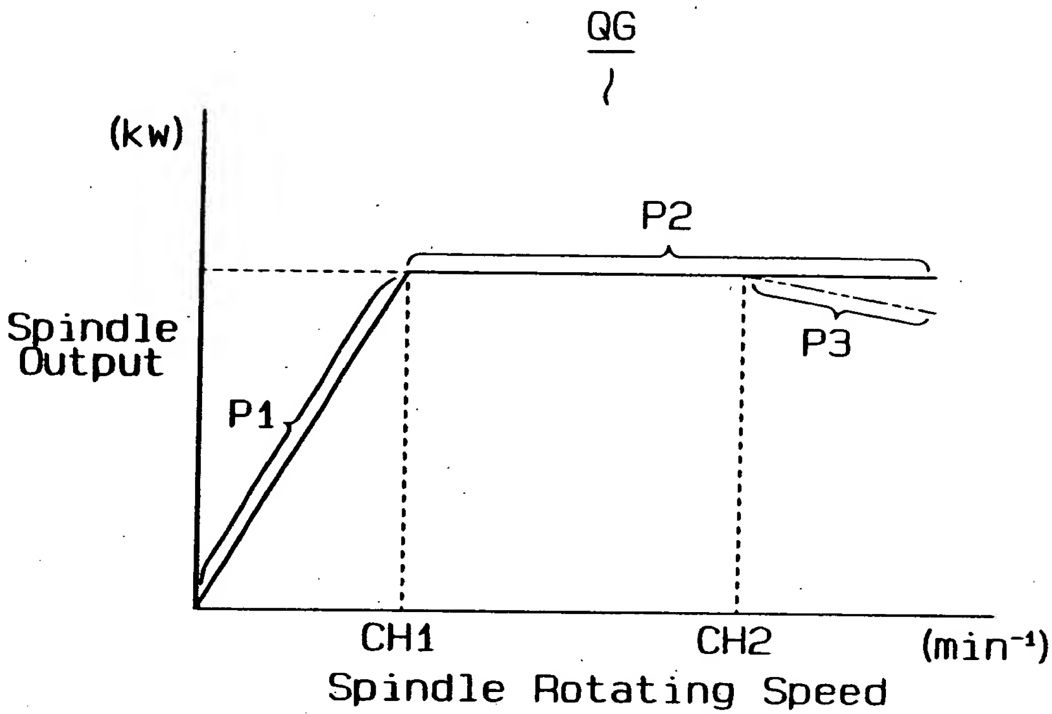
Workpiece Material	Basic Cutting Speed
FC	140
FCD	125
S45C	200
SCM	140
SUS	200
AL	1000
CU	300
:	:

(f) SKF3

Tool Material	Compensation Coefficient
Carbide	100
Cermet	120
Carbide Coating	115
:	:
:	:
:	:
:	:
:	:

tf1
tf2
tf3

[Fig.10]


QG
(kw)
Spindle Output
P1
P2
P3
CH1
CH2
(min⁻¹)
Spindle Rotating Speed

[Title of the Document] Abstract

[Abstract]

[Objective] To readily compose a machining program that easily improves machining conditions and thereby improves machining efficiency.

[Means for Solving the Problems] A message MSG showing advice for improving machining conditions is stored in a navigation information memory 47. Machining state information HJ that is obtained by executing a machining program GPR is stored in a simulation result information memory 12a. Sub-routines SR61 to SR64, which judge machining efficiency of machining processes KK1 to KK10 based on the spindle load upper-limit value SF, cutting speed upper-limit value WJ, and base rotating speed CH, are stored in a system program memory 16. A spindle load determiner 41, a cutting speed determiner 42, and a rotating speed determiner 50 analyze the machining state information HJ in the machining processes KK1 to KK10 based on the sub-routines SR61 to SR64. In accordance with the analysis result, a display controller 13 selects a message MSG and a display 6 displays the message MSG.

[Selected Drawing] Fig. 1